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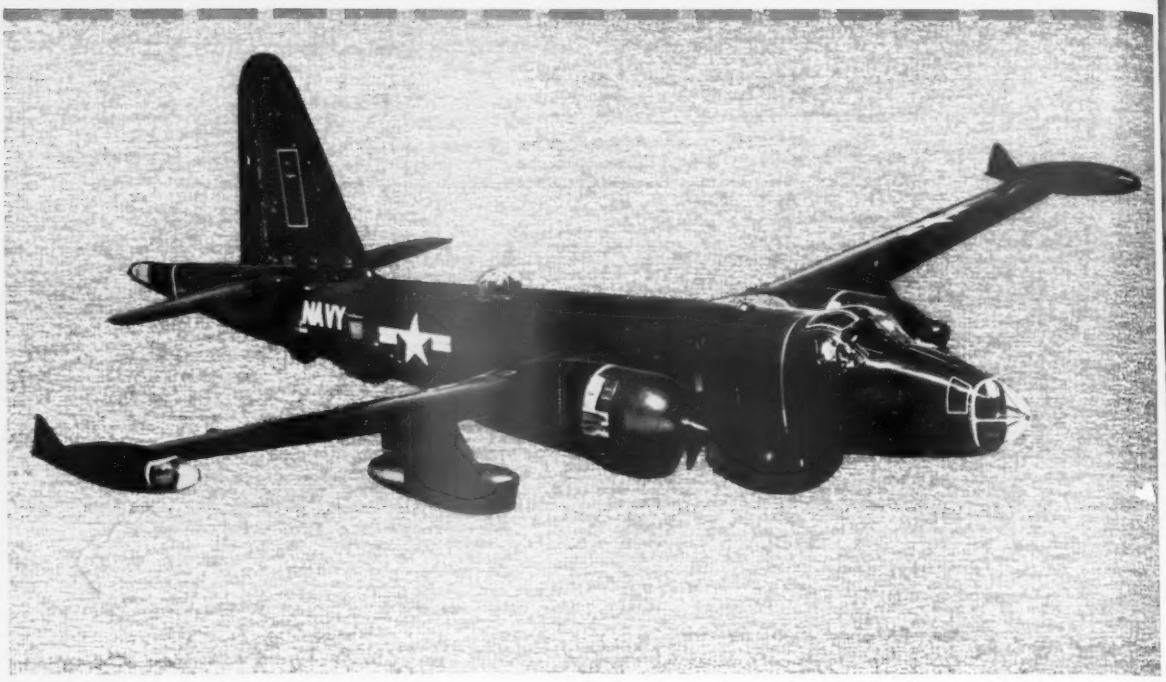
Aeronautical Engineering REVIEW

February, 1955



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Lockheed's Navy patrol bomber, the *Neptune*, is aptly named, for it is capable of firmly ruling the sub-surface deep that was once the private domain of the submarine. No longer is it necessary to *sight* subs, the *Neptune* can *sense* them hundreds of feet below the surface. Its amazing electronic search-gear coupled with record setting range and endurance make it a most formidable weapon.

Typical of the efficient cooperation that answers defense demands in this competitive, free-enterprising industry, Lockheed awarded TEMCO a sub-contract for the manufacture of complete outer wing assemblies for the *Neptune* in late 1950. TEMCO has supplied these components to Lockheed ever since — a quality product, delivered on schedule, at the lowest possible cost.

Neptune P2V wing panels taking shape on the assembly line at TEMCO's Dallas plant. One of many major components manufactured by TEMCO for other outstanding aircraft companies.

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DALLAS, TEXAS

Aeronautical Engineering Review

Vol. 14—No. 2 February, 1955

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Cover—A group of F-100 Super Sabre Jets, ready for delivery to the U.S. Air Force, are lined up at the Los Angeles plant of North American Aviation, Inc. According to the company, the F-100 is the nation's first production fighter that can fly level or climb faster than Mach 1. The aircraft is being built by North American at its Los Angeles and Columbus, Ohio, plants.

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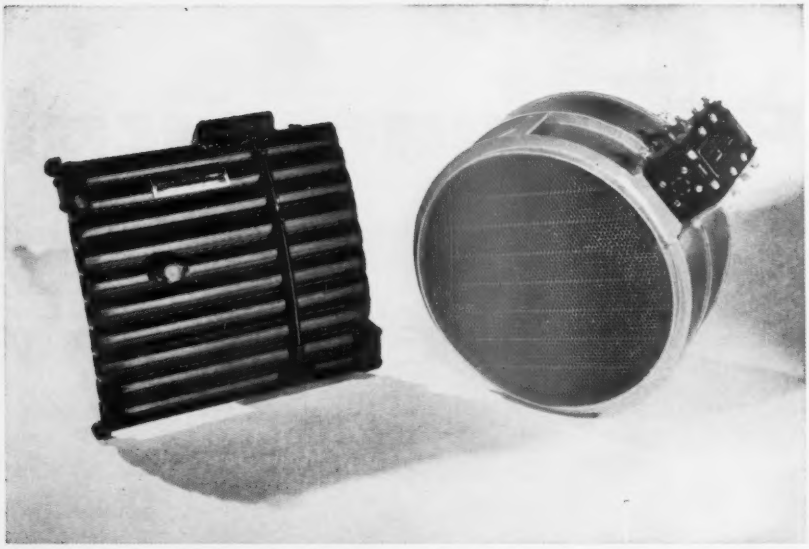


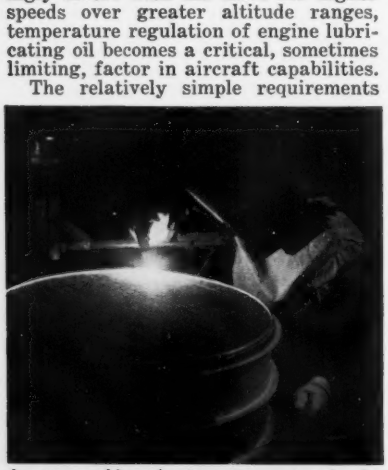
Modern all-aluminum oil coolers of the oil-to-fuel type (left) and the oil-to-air type (right) employ all-brazed construction for maximum strength-weight ratio and highest resistance to temperature, pressure, vibration and wear.

Progress In Oil Coolers . . .

Based on unique, proprietary processes for producing and brazing thin metal sections, plus the largest wind tunnel laboratory facility of its kind, the Clifford Company has pioneered the major developments in this field since 1940.

As flight conditions become increasingly severe with the drive for higher speeds over greater altitude ranges, temperature regulation of engine lubricating oil becomes a critical, sometimes limiting, factor in aircraft capabilities.

The relatively simple requirements of oil cooling in pre-war reciprocating engines, have today become complex heat exchange problems further complicated by the need to provide adequate heat rejection capacity within strict limits of size, weight — and sometimes even shape.



Inert gas welding of reciprocating engine oil cooler.

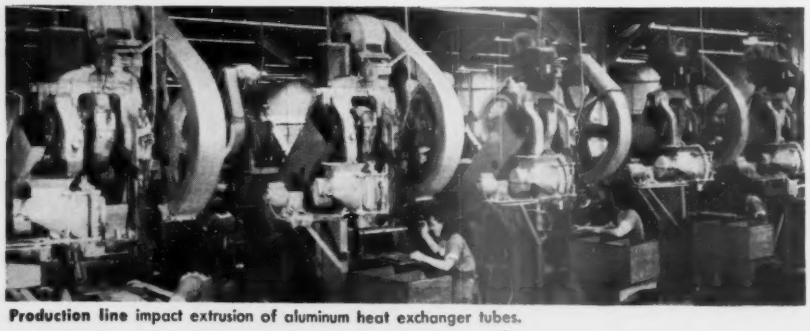
Three unique assets Clifford brings to bear on aircraft heat exchange problems have been largely responsible for the fact that it has initiated the major advances in the oil cooler field since 1940.

One asset is Clifford's ability to produce and fabricate thin metal sections, based on its own developments in deep drawing and extrusion.

Another is its exclusive proprietary process for brazing thin metals — particularly aluminum — which is unmatched by any other process.

Third is Clifford's wind tunnel laboratory — the largest, most completely equipped technical facility of its kind.

Clifford's background since the company's inception in 1926 was in the manufacture of thin walled metallic bellows and thermostatic assemblies.



Production line impact extrusion of aluminum heat exchanger tubes.

Bombsight servomechanism is typical aircraft application of Clifford bellows for automatic compensation of changes in temperature, pressure and other factors.

Typically, it broke into this field by developing the new, superior hydraulic forming method of producing bellows which today is the standard process throughout the world.

Handling thin metal sections to produce products for the control of heat proved excellent basic experience to back up Clifford's entry into the aircraft field.

The deep drawing and extrusion process attracted the attention of the armed services in the pre-war preparedness days and Clifford was asked to produce copper tubes for the manufacturers of aircraft oil coolers and coolant radiators.

Once acquainted with the field, it was not long before Clifford's metallurgical background uncovered an area of opportunity. Copper coolers were not wholly satisfactory. The dip soldering method of fastening the tubes so annealed the metal that many failures were experienced at pressures of only 100 psi or less. With oil pressures trending steadily upward in the newer engines, the situation was right for the introduction of a better design if one could be found.

Five years of metallurgical research at Clifford had resulted in a unique, proprietary process for brazing thin aluminum sections. Combining its earlier development in deep drawing and extrusion of thin tubing, Clifford independently designed and produced the first all-aluminum oil cooler and coolant radiator.

The new unit weighed only one-third as much as conventional copper coolers and life cycle tests showed a far higher service expectancy. The air services gave their enthusiastic approval and Clifford found itself in the forefront of a new field.

First to use the new aluminum oil coolers and coolant radiators were the Air Force's P-40 and P-38. Others quickly followed. At the war's end, Clifford was the sole producer of all-aluminum oil coolers whose products had been combat tested.

Lockheed's famous P-38 was among the first military aircraft to use Clifford's newly developed all-aluminum oil coolers and coolant radiators.

Coolant radiator of the type used in wartime liquid-cooled reciprocating engines.

Early jet engines coming along after the war required no oil cooling device. Oil was simply sprayed on the bearings and then ejected overboard. But with General Electric's contract to produce the J47-C, Clifford was asked to develop a suitable cooling system.

A completely new concept of oil cooling was suggested by Clifford. Since jets consumed large amounts of fuel it was possible to pass cold fuel on one side of the heat exchanger, hot lubricant on the other. With the flow governed by thermostatic valves, the lubricating oil is kept at optimum temperature.

The new design, since it did not depend on ram air for cooling, could be mounted out of the air stream and more easily armored. These and other advantages caused it to be adopted as standard for military jet aircraft.

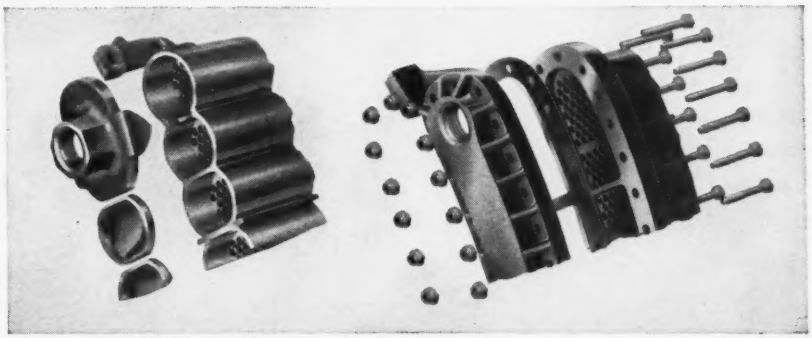
Later improvements resulted in substantial weight reduction and the elimination of numerous parts. Employing an extruded aluminum shell fastened by its proprietary brazing process, Clifford is today the only company able to produce these superior all-brazed, all-aluminum oil coolers.

Clifford's wind tunnel laboratory plays an increasingly important role in keeping the company in the forefront of aircraft heat exchanger developments. Ability to simulate service conditions with great accuracy eliminates the need for time consuming, expensive field testing of new designs. Its vast store of empirical knowledge permits rapid translation of thermodynamic theory into practical design without need for a succession of pilot models.

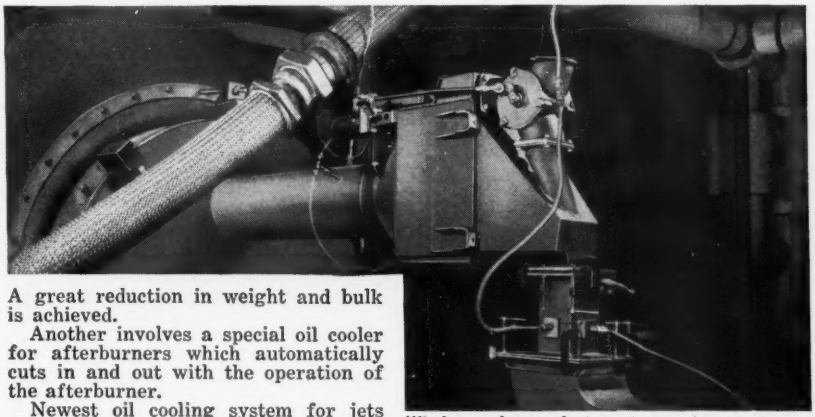
In few companies is there such a direct linear connection between research and production as can be found at Clifford.

New developments, still under military or proprietary wraps include a new oil cooler design based on using the latent heat of vaporization to cool the oil and vaporize part of the fuel before it enters the combustion chamber.

Sikorsky's H-39 helicopter which recently established a world's speed record, carries a Clifford oil cooler.



Advanced, simplified design of liquid type oil cooler for jet engines (left) shows obvious advantages over original design pioneered by Clifford. Gaskets, bolts and nuts are eliminated, weight reduced 28%, and a stronger, unitized, all-brazed construction achieved.



Wind tunnel test of air-to-air type heat exchanger assembly. Unit shown has integrally mounted control valves and actuator, and is used in aircraft air conditioning systems.

A great reduction in weight and bulk is achieved.

Another involves a special oil cooler for afterburners which automatically cuts in and out with the operation of the afterburner.

Newest oil cooling system for jets takes care of "high altitude cooling" conditions. When fuel flow drops too low to provide adequate cooling, thermostatic valves cut in an auxiliary air type cooler.

Helicopters pose especially difficult problems. Changes in direction from horizontal to vertical flight — or to hovering — makes their oil cooling demands highly variable. Clifford is currently developing two answers to these problems. One is an air-type cooler placed in an eductor. Engine exhaust is used to induce a flow of air for cooling. The second employs an air-type cooler placed in the air stream, but having in integral fan driven by a fluid motor. Oil temperature determines the operation of the fan through the action of thermostatic valves.

Rockets, missiles and avionic equipment are other areas in which Clifford is working. The company is also deep into nuclear energy heat exchange involving the handling of molten metals.

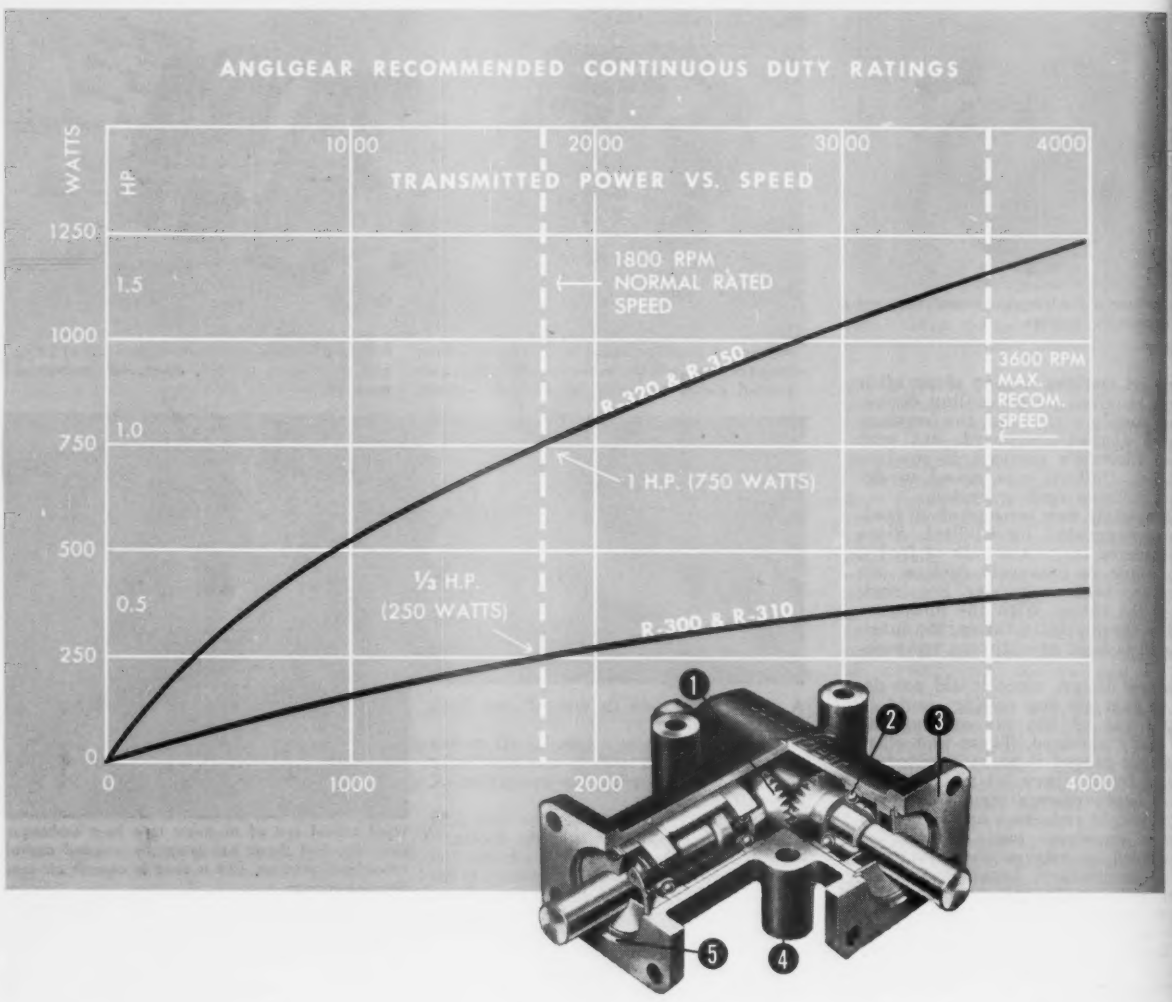
In all these areas, Clifford's unmatched facilities in aircraft heat exchange; and its unique ability to produce, fabricate and braze thin metal sections by proprietary processes is largely responsible for its present leadership in aircraft heat exchanger design.

For further information write: Clifford Manufacturing Company, 175 Ipswich St., Boston 15, Mass. *Division of Standard Thomson Corporation.* Offices in New York, Detroit, Chicago, Los Angeles and Waltham, Mass.

Self contained oil temperature regulating valves are designed and manufactured by Clifford for oil cooler applications.

Installation of oil-to-fuel type oil cooler on turbo-jet engine.

Bellows And Bellows Devices
CLIFFORD MANUFACTURING CO. WALTHAM, MASS.
Aircraft Heat Exchangers Valves Electronic Equipment



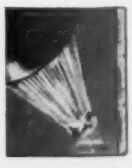
ORIGINAL RIGHT-ANGLE GEAR UPRATED

Now, six years after introduction, ANGLgear stands significantly improved. Static torque rating has been boosted 60%, broadening the field of application. And a fresh set of teeth—the new Coniflex design—has been added to insure smooth, quiet operation, and even longer life. These, however, are the only changes in ANGLgear. The units remain small in size and low in price.

1. Coniflex gears
2. Antifriction bearings
3. Flanged end mountings
4. 3-bolt side mounting
5. Internal pilot on mounting ends
6. 1-1 ratio

Model	Type	H.P.	R.P.M.	Ultimate Static Torque (In lb.)	Shaft Dia. Inches	Wt.
R-300	2 WAY	⅓	1800	400	⅜	½ lb.
R-300x	2 WAY	—	—	500	⅜	½ lb.
R-310	3 WAY	⅓	1800	400	⅜	½ lb.
R-310x	3 WAY	—	—	500	⅜	½ lb.
R-320	2 WAY	1	1800	1500	⅝	2¼ lb.
R-330	3 WAY	1	1800	1500	⅝	2¾ lb.

ANGLGEAR • LINEATOR • TRIM TROL • ROTORETTE • GEARED MAGNETIC BRAKE ROTORAC



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I.A.S. News Notes

February 1955

FLIGHT TEST ENGINEERING FELLOWSHIPS

The Institute of the Aeronautical Sciences has announced that two IAS Fellowships in Flight Test Engineering at Princeton University are now available and that applications for them must be filed in triplicate at the Institute's New York headquarters by March 1, 1955. Any one who presently holds a bachelor's degree in engineering or upon whom one will be conferred no later than June of this year is invited to submit an application.

Fellows will begin their graduate work at Princeton this coming September. The renewal of these fellowships for a second year is contigent upon the usual first year's satisfactory performance. The fellowship carries with it a stipend of $2,100 for married men and $1,800 for single ones. Also provided to the fellows are $600 for tuition and $800 for research.

* * * * * * * * *

1955-1956 IAS ROSTER ANNOUNCED

Within the next two weeks all IAS members will receive data cards pertaining to the 1955-1956 Roster of Members. Those members who wish to change their listing as it appeared in the last edition of the Roster are urged to fill in and return the data card immediately upon receipt.

* * * * * * * * *

NATIONAL MEETINGS CALENDAR

Mar. 11	National Flight Propulsion Meeting (Restricted), Hotel Carter, Cleveland.
June 21-24	Fifth International Aeronautical Conference, IAS Building, 7660 Beverly Blvd., Los Angeles.
Aug. 8-10	Turbine-Powered Air Transportation Meeting, Seattle, Wash.

* * * * * * * * *

CALENDAR OF SECTION MEETINGS

Feb. 1-- San Diego Section: IAS Building. Meeting, 7:45 p.m. "Use of Electronic Computers in Industry" by Dr. Donald Wall, Applied Science Division, IBM.

Feb. 8-- Baltimore Section: New Applied Physics Laboratory, Johns Hopkins University. Dinner Meeting, 6:00 p.m. "Water-Based Aircraft" discussed by F. W. Locke, USN BuAer; C. T. Ray, Glenn L. Martin Co.; and E. G. Stout, Convair. Joint meeting with Hagerstown and Washington Sections.

Feb. 8-- Hagerstown Section: See Baltimore Section.

CALENDAR OF SECTION MEETINGS (CONT.)

Feb. 8-- Los Angeles Section: IAS Building. Specialist Meeting, 8:00 p.m. "Usage of Castings in Highly Stressed Aircraft Structural Applications" by R. Van Deventer, Alloy Engineering & Casting Co.

Feb. 8-- Washington Section: See Baltimore Section.

Feb. 10 -- San Diego Section: IAS Building. Meeting, 7:45 p.m. "New Technique in Casting" by R. Van Deventer, Alloy Eng. & Casting Co.

Feb. 15-- Hagerstown Section: Packet Room, Terrace Restaurant. Meeting, 8:00 p.m. Subject - "The Functions of the Engineering Laboratory and Materials Department."

Feb. 16-- Wichita Section: "The Development of the XT-37 Primary Trainer" by O. D. Mall, Project Engineer, Cessna Aircraft Co.

Feb. 17-- Los Angeles Section: IAS Building. Social Hour, 6:00 p.m.; Dinner, 7:00 p.m.; Meeting, 8:15 p.m. "Flight Testing" by A. W. (Tony) LeVier, Chief Engineering Test Pilot, Lockheed.

Feb. 22-- Los Angeles Section: IAS Building. Specialist Meeting, 8:00 p.m. "Reduction of Drag Due to Lift and Thickness in Supersonic Flow" by Mrs. Rose M. Licher, Assoc. Engr., Santa Monica Div., Douglas.

Feb. 24-- Dayton Section: Engineers Club of Dayton. Dinner, 6:30 p.m. Meeting, 7:30 p.m. "Soviet Air Technical Achievement" by Brig. Gen. H. E. Watson.

Feb. 24-- San Diego Section: IAS Building. Dinner Meeting, 6:30 p.m. "Evaluation of Military Equipment" by Dr. Royal Weller, Chief Scientist, NAMTC, Point Mugu, California.

Mar. 8-- Indianapolis Section: Memorial Union Building, Purdue University. Dinner Meeting, 6:45 p.m. Subject - "The Boeing 707 Airplane." Meeting sponsored by IAS Student Branch at Purdue.

Mar. 8-- Los Angeles Section: IAS Building. Specialist Meeting, 8:00 p.m. "Properties of the Atmosphere at Extreme Altitudes" (tentative) by Dr. William W. Kellogg, Geophysics Group, The RAND Corp.

Mar. 9-- Niagara Frontier Section: Speaker - Lt. Gen. W. E. Kepner, USAF (Ret.), Executive Vice-President, Bell Aircraft Corporation.

Mar. 21-- Los Angeles Section: IAS Building. Confidential Specialist Meeting, 8:00 p.m. "Optimizing Duct Recovery Through Boundary Layer Control" (tentative) by E. Mossman, Ames Aero. Lab., NACA.

Mar. 23-- St. Louis Section: Engineers Club of St. Louis. Meeting, 8:00 p.m. Panel discussion on "Structural Fatigue Problems in Aircraft Design." Conducted jointly with American Helicopter Society.

Apr. 23-- Los Angeles Section: IAS Building. Annual Spring Dance, 9:15 p.m.

* * * * * * * *

IAS News

A Record of People and Events of Interest to Institute Members

Fifth International Aeronautical Conference

British and American Delegates to Meet in Los Angeles on June 20. Approximately 20 Papers to Be Presented During Technical Sessions.

Warren Dickinson

THE FIFTH INTERNATIONAL AERONAUTICAL CONFERENCE will convene at the IAS building in Los Angeles on Monday, June 20. This conference will be the second one of its kind to be held in this country, the other three having been held in England.

The meeting will formally get under way on the morning of June 20 with an opening address to the British and American delegates. For the remainder of that day, two sessions are now on the agenda. However, for June 21 and 22, morning, afternoon, and evening sessions are tentatively planned.

For Thursday, June 23, two field trips are being scheduled. One of these will be for the British delegates, while the other will include only the American delegates. An informal dinner-dance at Los Angeles' Palladium is being planned for both groups that same evening.

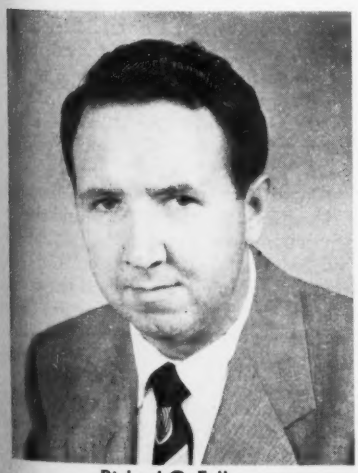
As of this writing, it is planned to devote the rest of this week and through Friday of the next week toward giving the British delegates an insight into the American aircraft industry. This part of the program—for British only—is scheduled to begin on June 24, when the British delegates are transported to San Diego for a tour of the local aircraft industry. While in San Diego, they will be guests of honor at a dinner-dance. The group will return to Los Angeles on June 25 in time to participate in a barbecue dinner given for them and for the IAS members and families.

Sunday, the twenty-sixth, will be open.

The series of tours are being arranged from June 27 through 29. These tours will cover the plants of the major airframe companies and various research facilities in the Los Angeles area. On June 30, present plans call for the British delegates to be flown to the San Francisco area. They will visit the NACA Ames Aeronautical Laboratory on July 1, the final day of this all-British tour of the California aircraft industry. A reception in San Francisco will follow later that day and will officially conclude the Fifth International Aeronautical Conference.

A social program for the wives of the British delegates is being arranged by a Ladies Committee. This program will include such items as visits to movie studios, sightseeing tours, informal luncheons, etc.

Among the members of the Los Angeles Section who have been responsible for the planning of this conference are: Warren Dickinson, Section Chairman; Richard G. Fuller, Los Angeles Section Program Committee Chairman; and Winfield H. Arata, Jr., Chairman of the Program Subcommittee.



Richard G. Fuller

Winfield H. Arata, Jr.

J. L. Pritchard Presents Lecture Series

Captain J. Laurence Pritchard, Honorary Fellow of the Royal Aeronautical Society and the Institute of the Aeronautical Sciences, who was formerly the RAeS Secretary and is now an RAeS Council Member, is presenting a series of illustrated lectures throughout the United States. These lectures are on the history of aviation and cover such topics as the RAeS and the Wright brothers, the Wright brothers from an Englishman's point of view, Anglo-American aviation, and the gas-balloon to gas-turbine period.

The tentative schedule for Captain Pritchard's lectures is as follows:

January 20—Polytechnic Institute of Brooklyn.
January 21—Columbia University.
January 24—IAS Honors Night Dinner, Annual Meeting.
January 26—Historical Associate Members, IAS Annual Meeting.
January 28—Columbia University.
January 31—The Johns Hopkins University.
February 2—Princeton University.
February 4—Polytechnic Institute of Brooklyn.
February 7—Massachusetts Institute of Technology.
February 9—Cornell University.
February 11—Cornell Aeronautical Laboratory, Inc.
February 14—Michigan University.
February 16—General Electric Company, Evendale, Ohio.
February 18—Purdue University.
February 21—University of Illinois, Urbana, Ill.
February 24—Iowa State College.
February 28—University of Colorado.
March 2—Stanford University.
March 7—California Institute of Technology.
March 8—University of California at Los Angeles.
March 11—Mississippi State College.

This series of lectures is being given by Captain Pritchard under the auspices of the American aviation industry, including certain manufacturing concerns and educational institutions.

Memory of Dr. J. S. Ames Honored

The new $1,500,000 engineering building at The Johns Hopkins University will be named in honor of the late Dr. Joseph Sweetman Ames, IAS Honorary Fellow and Founder Member, who served as the University's fourth President. The building will be formally dedicated some time this coming spring.

Dr. Ames, after whom the NACA Ames Aeronautical Laboratory was named, died in 1943 at the age of 78.

The Late Dr. J. S. Ames

He was identified with Johns Hopkins from 1883 to 1935 as a Student, Professor of Physics, Dean, Provost, and President. Upon retiring in 1935, he became President Emeritus.

Noted for his work in aeronautical research as well as in education, Dr. Ames was one of the original members of the NACA appointed in 1915 by President Woodrow Wilson. Dr. Ames served as Chairman of the NACA Executive Committee from 1919 to 1936, as Chairman of its main committee from 1927 to 1939, and at different times on more than 20 of its subcommitttees. When failing health caused Dr. Ames to resign from the NACA Chairmanship in 1939, President Franklin D. Roosevelt wrote:

"For the past twenty years you have served as Chairman of the National Advisory Committee for Aeronautics or Chairman of its Executive Committee. The Administration and the accomplishments of the Committee under your leadership reflect your great scientific attainments, professional courage, and executive ability.

"That the people generally have not known of your brilliant and patriotic service is because it has been overshadowed by your passion for accomplishment without publicity. But the fact remains, and I am happy to give you credit for it, that the remarkable progress for many years in the improvement of the performance, efficiency, and safety of American aircraft, both military and commercial, has been due largely to your own inspiring leadership in the development of new research facilities and in the orderly prosecution of comprehensive research programs."

Detroit IAS Members Serve with Vocational Group

Frederick A. Hiersch, MIAS, Chairman, Detroit Section, and Staff Engineer, Continental Aviation & Engineering Corporation, and John E. Luecht, MIAS, General Supervisor—Advanced Design, Missile Branch, Chrysler Corporation, participated as Counselors at the Twentieth Annual Vocational Guidance Meeting. This meeting was held on last November 30 to aid Detroit area high school students in their selection of engineering as a profession.

It was estimated that approximately 100 counselors took part in the meeting. They represented all branches of engineering and science, including architecture; mechanical, chemical, civil, electrical, aeronautical, and automotive engineering; chemistry; physics; refrigeration; ceramics; radio; illumination; etc. Twenty-four engineering and scientific societies participated.

The national sponsor is the Engineers' Council for Professional Development. The local sponsors are The Engineering Society of Detroit Vocational Guidance Committee and the City of Detroit's Board of Education.

ARS Gives Awards and Fellowships to IAS Members; R. W. Porter Elected 1955 ARS President

Three members of the Institute of the Aeronautical Sciences were selected to receive awards from the American Rocket Society at the ARS Ninth Annual Honors Dinner on last December 2. These recipients were: Dr. Theodore von Kármán, HFIAS, Chairman, Advisory Group for Aeronautical Research and Development, NATO, Paris, France; A. M. O. Smith, MIAS, Supervisor, Design Research, El Segundo Division, Douglas Aircraft Company, Inc.; and Martin Summerfield, AFIAS, Professor of Aeronautical Engineering, Princeton University.

A new award for contribution to the field of astronautics was given to Dr. von Kármán. The first recipient of the Astronautics Award, Dr. von Kármán was one of the first United States scientists to encourage study of the feasibility of space flight. This was in the late 1930's, while he was serving as Director of the Guggenheim Aeronautical Laboratory, California Institute of Technology.

The Robert H. Goddard Memorial Award for achievement in liquid rocket propellants was won by Mr. Smith. He worked on liquid rockets at CalTech in 1938 and later as Chief Engineer at Aerojet Engineering Corporation (now Aerojet-General Corporation, Subsidiary of The General Tire and Rubber Company).

Mr. Summerfield received the G. Edward Pendray Award for contribution to literature in the rocket and jet-propulsion field. In addition to his work at

Princeton, Mr. Summerfield is also Editor of *Jet Propulsion*, Journal of the American Rocket Society.

During the same Annual Honors Dinner, Fellowships in the American Rocket Society were conferred upon three other IAS members. These three are: Lawrence D. Bell, AMIAS, President, Bell Aircraft Corporation; S. K. Hoffman, AFIAS, Chief, Propulsion Section, Aerophysics Laboratory, North American Aviation, Inc.; and Elmer P. Wheaton, AFIAS, Chief Project Engineer, Missiles, Santa Monica Division, Douglas Aircraft Company, Inc.

Dr. Richard W. Porter, MIAS, General Manager, Guided Missiles Department, General Electric Company, was elected to serve as the 1955 ARS President. Dr. Porter was an ARS Vice-President during 1954 and was a member of the Society's Board of Directors for 3 years beginning in 1951.

Government-Industry Research Committee Formed

At the request of industry and Government officials, an eleven-man committee was organized to explore the need for better acquaintance and understanding between Government and industry research leaders and to consider methods for accomplishing this objective. This group is known as the Government-Industry Research Council. In the committee are three IAS members: Allen V. Astin, HMIAS, Director, National Bureau of Standards; Daniel P. Barnard, AFIAS, Deputy Assistant Secretary of Defense, Research and Development; and Hugh L. Dryden, IAS Honorary Fellow and Honorary Member, Chairman, NACA.

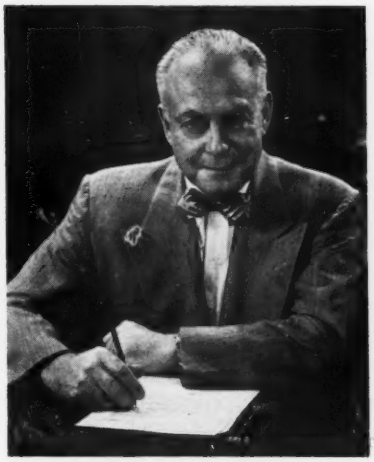
At its first meeting, the committee concluded that effective mechanisms already exist in many fields for furthering mutually helpful relations between Government and industry research. However, the committee agreed to hold itself available as necessary to assist in exchanging views and ideas designed to improve such relations where either Government or industry groups may feel this to be desirable.

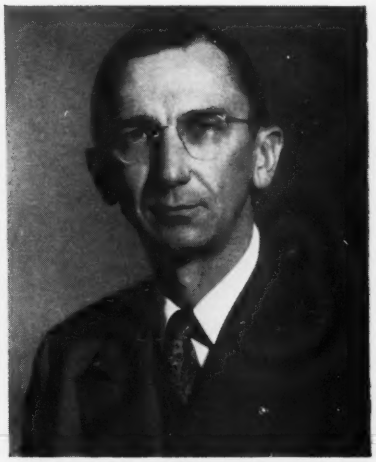
When its services are requested, the committee proposes to consider first the extent to which the need can be satisfied by existing mechanisms. If appropriate, the committee will then consider designation of an *ad hoc* group of individuals active in the particular field concerned to assist in bringing about improved understanding and closer relationships between Government and industry in that field.

DOC Publication Available

The Department of Commerce, Office of Technical Services, has announced the availability of its monthly publication, *U.S. Government Research Reports*. This edition, formerly *Bibliography of Technical Reports*, contains from 300 to 400 research reports each month. These reports are a part of that nonconfidential technical information amassed by the Government research and development projects and cover nearly every field of industrial activity.

U.S. Government Research Reports may be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C., or from any of the U.S. Department of Commerce Field Offices. Annual subscription is $6.00 domestic and $9.00 foreign. Single copies are $0.60 each.





The Collier Trophy for "outstanding achievement in aviation" for 1953 was awarded to James H. (Dutch) Kindelberger (*left*) and Edward H. Heinemann "for the development of the first supersonic fighter airplanes in service." The presentation was made by President Eisenhower in a ceremony at the White House on December 17. Mr. Kindelberger, IAS Honorary Fellow and Past-President, Chairman of the Board of North American Aviation, Inc., received the trophy "for the North American Land-Based F-100." Mr. Heinemann, FIAS, Chief Engineer, El Segundo Division, Douglas Aircraft Company, Inc., was named corecipient "for the Douglas Carrier-Based F-4-D." The Collier Trophy, founded in 1911 by the late Robert J. Collier, is administered by the National Aeronautic Association. Since the original of this trophy remains with the NAA, miniatures were given to the Messrs. Kindelberger and Heinemann.

Necrology

William Coney

William Coney, AMIAS, Material Planner and Estimator, U.S. Naval Air Station, Corpus Christi, Tex., suffered a heart attack and died on last November 18.

Born on May 26, 1892, Mr. Coney attended business college and trade school. He entered the aeronautical field in 1941, when he first went to work at the Corpus Christi NAS. In his position there as Planner and Estimator for the Material Section of the Assembly and Repair Department, he was charged with determining the ferrous and nonferrous raw materials to be used in the manufacture of aircraft parts and with submitting pertinent suggestions about these materials to the engineering department for its approval.

Mr. Coney is survived by his widow, Mrs. Grace Coney.

News of Members

▸ **Preston R. Bassett,** an IAS Honorary Fellow and Past-President, President, Sperry Gyroscope Company, Division of The Sperry Corporation, was recently given a diamond award for outstanding service through 40 years of aviation's first half-century. The presentation of this diamond-studded 40-year service pin was made at a dinner attended by company officials.

▸ **Dr. Alfred G. Cattaneo** (AF), Head, Fuels and Lubricants Engineering Department, Shell Development Company, has been appointed Chair-

(*Continued on page 68*)

Guest Editorial

Hugh De Haven—

Director of Cornell University's Crash Injury Research Program, who retired from active participation in the program at the end of 1954. During the past several years, H. De Haven and his group have cooperated closely with the Institute. Several of his papers have been published in the REVIEW. His outstanding work on "survivability" in aircraft accidents has resulted in many design modifications, and his theories are now being applied to design of all automotive equipment, civilian and military. The life-saving potential of his work is incalculable. Our Guest Editorial is a tribute to Hugh De Haven prepared by the Vice-President—Research, of Cornell University, and a Founder Member of the Institute.

A Tribute to Hugh De Haven

IT IS FITTING at this time to pay our tribute to Crash Injury Research's retiring Director.

It can be truly said that this project might not have come into being at all had it not been for Hugh De Haven's courage and perseverance in the face of incredible obstacles—physical, financial, and administrative—and his absolute refusal to know "when he was licked." Under his hand, CIR has grown from a forlorn unit of three people operating as a poor and hardly respectable relation of the Cornell Medical College, into a group of 15 full-time workers with an annual budget running well above $100,000. Moreover, CIR today is known and respected throughout the world.

This is the work of Hugh De Haven. He was the pioneer of the concept of "Survivability" and brought CIR to Cornell Medical College on a small grant from OSRD in 1942. The tiny project was attached to the Department of Physiology under the chairmanship of Eugene DuBois. During the next 3 years Hugh strove to obtain the cooperation of CAB with Jerry Lederer of CAB's Safety Board. They were able to enlarge the scope of the Board's investigations to include photographs and statements of the causes of injuries whenever identifiable. OSRD funds ran out in 1945, but Army, Navy, Air Force, CAA, AOPA, and ATA all "chipped in" and another year of life was assured, this time under the aegis of the National Research Council.

In 1947 a contract with ONR was signed with BuMed, with the Air Force contributing as well, and the hand-to-mouth existence continued. Year after year the assurance of continuance could not be obtained until literally the last few days or hours of June. Yet the project slowly expanded despite the strains and stresses of its cramped two-room quarters and precarious financial support.

In 1950 changes in personnel and policies of the Department of Physiology literally forced CIR out of the main Medical College building and space was found for it on the third floor of the Public Health Building on 69th Street, a few hundred yards away. This proved to be a fortunate move for all concerned, for the project now received the administrative support of the Department of Preventive Medicine and Dr. Smillie.

By 1952 it had become increasingly apparent that many of the lessons of "survivability" in aircraft were equally applicable to the automotive field, and the Army became sufficiently interested to contribute $25,000 to the general pool whose other principal supporters remained the Navy and Air Force. At the same time, CIR moved into the field of air-transport accidents.

So rapid was the resulting expansion that, after only 1 year of joint support, the Army negotiated a separate contract allocating its funds solely to automotive accident studies while the Navy and Air Force continued the support of the Aviation Division. By March, 1954, the twins had grown so large that an actual physical separation became necessary. The Aviation Division was accordingly attached to the Cornell-Guggenheim Aviation Safety Center and set up shop at 471 Park Avenue along with the Flight Safety Foundation under the two-way directorship of Jerry Lederer. Automotive CIR remained at 69th Street, and the space situation was at least momentarily eased.

Hugh has always known how to attract capable assistants and how to delegate authority to them. He has placed the future of CIR in the competent hands of Howard Hasbrook and John Moore, in charge respectively of the Aviation and Automotive divisions. They will carry forward the good work for which he labored so long and with such effectiveness. We deplore his departure from active participation, but we shall neither forget his magnificent contributions to "survivability" in transportation accidents nor cease to honor Hugh De Haven.

DR. T. P. WRIGHT
Past-President, IAS

Air Safety Highlights

by

*Welman A. Shrader**

Carl M. Christenson, holding United's Safety Award plaque, receives congratulations from Jerry Lederer.

THE SIXTH ANNUAL AIR SAFETY SEMINAR conducted by the Flight Safety Foundation revealed, among other things, that Jerry Lederer's lifelong crusade is constantly gathering more and more adherents, advocates, and momentum. This recent meeting, held in November, attracted 156 participants from 56 different organizations—plus 17 commands of the Air Force.

The success of these Seminars is due, in part, to the informality and confidential "hair-down" nature of the discussions and to the limited size of the participating groups. Even the remote sites selected for these annual powwows tend to encourage the right atmosphere and desired attendance.

Bishops Lodge at Santa Fe, N.M., was chosen this year because of its proximity (by Western standards) to the Lovelace Foundation in Albuquerque (60 miles away!). Here, Dr. Randolph Lovelace and his staff gave the group an impressive demonstration of modern facilities and some of the work being done in the field of aero-medical research.

Although much of the material presented at the 3-day sessions was off-the-record, the following highlights give a fair idea of the subjects covered and the importance of the discussions involved.

Drs. Clayton S. White and Ulrich C. Luft of the Lovelace Clinic opened the sessions with a discussion of biological dynamic loading and the impact of blast due to high-speed evacuation. A study of the effects of tumbling in a *g* field was followed by a résumé of the effects of rapid deceleration. Interesting conclusions were reported on the hazards of using pressure-type oxygen masks when explosive decompression occurs because of residual pressure in the lungs remaining equal to mask pressure. It was shown that the effects of other than normal breathing can be fatal under certain coincident conditions.

In a discussion of "Operational Loads on Air Crews," Col. Harry G. Moseley of the Directorate of Flight Safety Research, presented a new and novel study of the fundamental reasons for pilot performance that leads to accidents. (This will be presented in more complete form at a later date.)

Colonel Moseley then discussed the work load on pilots following the theories laid down by United Air Lines' Capt. Larry Shapiro and illustrated by the accompanying chart opposite. The head-on collision hazard was dramatically presented by analyzing the necessary time lag in taking evasive action, as follows:

0.1 sec. for the nerves to carry to the brain what the eye sees.
0.4 sec. for the brain to recognize what it sees.
4.0 sec. (approximately) for the brain to make a decision when there are several choices.
0.5 sec. for the nerves to carry the decision to the muscles and make them move.
2.0 sec. for lag due to stretch in control cables, time to move control surfaces, and time to change direction of the aircraft.

7.0 sec. total

A pilot might see the oncoming airplane at a distance of 3 miles—which would be fortunate because as United's Carl Christenson pointed out later, at a distance of 3 miles, a DC-6 looks like an inverted "T" with the bars only $^{3}/_{16}$ in. long. Multiply 7 sec. by the closing speed of modern aircraft and the situation is obviously hazardous!

Dr. White later presented, by case histories, the dilemma that faces the medical examiner when he uncovers some borderline physical deficiency and must advise the pilot whether it is safe for him to continue flying. In one case, the pilot was advised to

* Director of Publications, Institute of the Aeronautical Sciences.

discontinue passenger flying or any flying that would risk the lives of others. Fortunately, he followed this advice. A year or so later, he died suddenly while sitting in his hotel room.

In another case, the pilot was advised what to do to overcome his deficiency. By following instructions, he has been able to continue his profession safely.

Dr. Ross A. McFarland, of Harvard University's School of Public Health, showed some interesting slides on the problems of pilot aging, physical deficiencies and their subsequent histories, and pilot fatigue in relation to accidents. Much of the material presented was taken from his book, *Human Factors in Air Transportation*.

Major John P. McCann, USAF (MC), M.D., also of the Harvard School of Public Health, outlined the techniques for identifying bodies following an accident. He emphasized the important part the doctor can play in the investigation of accidents by autopsy to determine if disease, toxic effects, or pre-existing injury—such as a dormant blood clot—might have been contributing factors to the accident.

The problem of transferring passengers from a ditched airplane to a life raft was thoroughly covered by Robert Bicknell, of the Air Cruiser Company, Division of The Garrett Corporation. His practical demonstration of the use of life vests and the operation of a life raft (in a swimming pool with water temperature of about 50°!) was one of the highlights of the Seminar. (See photos below.)

Mr. Bicknell estimated that one ditching occurs in 2,500,000 operations. His discussion favored the exterior storage of rafts, simultaneous inflation and loading of rafts to save time in evacuation, and improved aircraft flotation by the utilization of plastic foams for insulation and vibration dampening in the aircraft structure.

Otto E. Kirchner, formerly of American Airlines and now with Boeing Airplane Company, presented a discussion of "Air Transport Accidents" which aroused considerable interest. He pointed out that the preponderance of accidents are caused by weather, especially

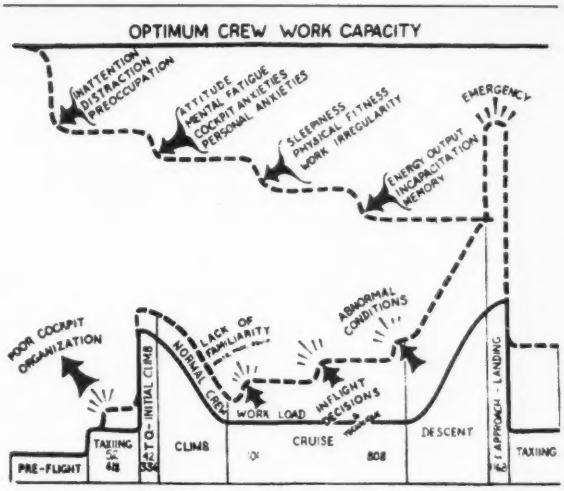
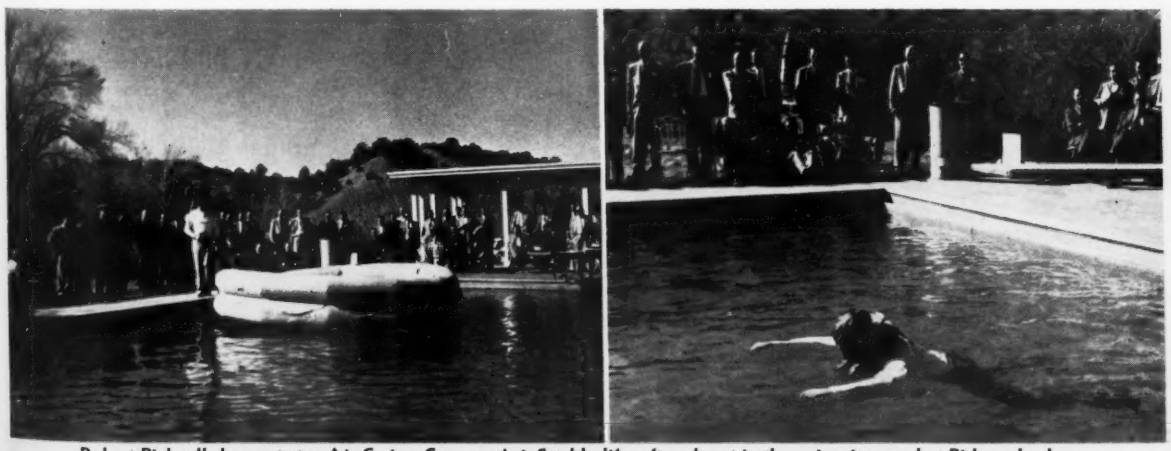


Figure from L. Shapiro's paper, "Relationship Between Cockpit Procedures and Accidents," presented at ALPA 1954 Air Safety Forum.

turbulence, and stated the probability that the critical loads in survivable accidents occur in a vertical rather than a horizontal direction. (Mr. Kirchner's complete paper will be published later by the FSF.)

Dr. Barry G. King, Research Executive, Medical Division of the CAA, and W. K. Andrews, Chief, Bureau of Safety Investigation of the CAB, outlined some of the "Survival Lessons Learned from Recent Accidents." One interesting case cited was the take-off, landing, and evacuation of 34 passengers from an air transport that had an engine catch fire on take-off. The entire evacuation job was accomplished in slightly over 2 min. with the use of slide chutes.

A. Howard Hasbrook, Associate Director, Aviation Crash Injury Research, CGASC, pleaded for wider cooperation in securing information on how people are injured in a crash, illustrating the application of such analysis by slides. Complementing this plea was a paper by William Stieglitz, Design Safety Engineer of Republic Aviation Corporation, calling for a more constructive approach to accident investigations. These should be regarded not like a coroner's investiga-



Robert Bicknell demonstrates Air Cruiser Company's inflatable life raft and vest in the swimming pool at Bishops Lodge.

Flight Safety Foundation's Director, Jerry Lederer, presents the three Aviation Week Safety Awards for 1954 to Col. John P. Stapp, United Air Lines' Otis E. Kline, and CAA's John Easton.

tion—to fix the time and cause of death—but rather like an autopsy performed by specialists to determine what can be learned in the broadest sense. The resulting knowledge should then be disseminated in an organized pattern so that oversights would not be repeated, according to Mr. Stieglitz's paper "Getting the Most from Accident Investigations."

Charles O. Miller, Flight Safety Staff Engineer, Chance Vought Aircraft, Inc., showed how the lessons learned from accident investigations and other sources can be fitted into a system analysis procedure involving all aspects of design so that the chance of overlooking a critical point would be reduced. He expressed the feeling that the term "pilot error" could not be used constructively in avoiding accidents.

Boeing's attitude toward safety problems was revealed by E. W. Norris, Airworthiness Engineer at the Seattle plant of Boeing Airplane Company. Mr. Norris presented some slides and a motion picture showing how this attitude had been implemented in the design and construction of the new 707 jet transport. As an example, it was noted that the fluid lines and the electrical systems are placed on opposite sides of each engine to separate ignition sources from the flammable fluids.

Several constructive suggestions on the avoidance of turbulence were given by TWA's Director of Flight Operations, Paul S. Fredrickson. These, along with several other releasable papers, will be published later by the Flight Safety Foundation.

Collision prevention came in for a wide share of the discussion. United Air Lines' Director of Safety, Carl M. Christenson, set the stage by giving a "Résumé of Collision Hazards." A suggested method for studying "Proximity vs. Capacity on Airways" was presented by Karl Swartzel, Head of Lear, Inc.'s Research & Development Department. The use of high-intensity Xenon Anti-Collision Lights was proposed by Transocean Air Lines' Andrew Madsen, and a model illustrating the use of such lights was demonstrated. Doppler System radar and its possible use as an auditory means of warning the pilot of approaching or proximity aircraft was graphically illustrated by Drs. James Q. Brantley and Walter A. Flood of the Cornell Aeronautical Laboratory. Via means of tape recordings, they proved that both the approximate position and size of approaching aircraft could be distinguished.

Walter Kidde Company's Crash Fire Trigger and fire prevention system were described and discussed by I. J. Hammill, Manager, Aviation Division, and by A. B. Hobelmann, Assistant Vice-President of the company.

Herbert O. Fisher, Chief, Aviation Development Division of the Port of New York Authority, outlined some of the safety problems involved in operating the busiest group of airports in the world. He pointed out that 1,600 landings and take-offs comprise an average day, with peaks as high as 2,170 movements, in the New York area.

To Carl Christenson fell the honor of closing the technical sessions at Santa Fe with a philosophical "Re-examination of Safety Techniques."

The annual Award Dinner was held at Bishops Lodge on the evening of November 11, at which time the Flight Safety Foundation presented the three Aviation Week Awards for 1954 and its own Certificates of Merit. Recipients of the former were Col. John P. Stapp, USAF (MC), Chief, Aero-Medical Field Laboratory, Holloman AFB, "for originality and ingenuity used in the systematic investigation of the effects of rapid deceleration on the human body, establishing design parameters which provide an optimum of protection for aircraft occupants under loads applied to the body during high-altitude evacuation; and for great personal courage in conducting his experiments."

The second Award went to United Air Lines "for the important part it has played in the development and testing of anticollision lights as an interim measure to reduce the mid-air collision hazard in aviation."

The Technical Development and Evaluation Center of the CAA was the third recipient "for its investigation and evaluation of devices designed to detect fires in flight and for fire protection, and especially to Harvey Hansberry for his leadership in this field."

Special Certificates of Merit went to Ray Kelly, Superintendent, Technical Development, United Air

(*Continued on page 39*)

The Role of
Fluid Mechanics in Aeronautical Development

G. N. PATTERSON* AND STAFF

Institute of Aerophysics and Department of Aeronautical Engineering, University of Toronto

Introduction

During 1953 man commemorated the first 50 years of powered flight. Much has been said about those courageous pioneers who made many flights of historic significance. But there is another side to the subject. The basic improvements in airplane design reflect our improved knowledge of the properties of gases, liquids, and solids. In this paper, attention is drawn to the important influence exerted by research in fluid mechanics on aeronautical development.

We shall first outline the various stages of progress of fluid mechanics (Fig. 1) from classical hydrodynamics to the mechanics of rarefied gases. The second part of the paper deals with the influence of these developments on the aerodynamics of the airplane under such headings as air resistance, wing theory, stability and control, and propulsion. Finally, we suggest the possible influence of modern aeronautical design requirements on future trends of research in fluid mechanics.

(I) Developments in Fundamental Fluid Mechanics

Fluid mechanics is that branch of science which treats the properties of fluids at rest and in motion and their interaction with fluid or solid boundaries. The subject is subdivided today into a number of branches. The most important of these are hydrodynamics, the study of mobile liquids such as water, and aerodynamics, the study of gaseous fluids. The term classical hydrodynamics is often used to convey the mathematical study of inviscid, incompressible flows during its early development (Fig. 2).

Unlike other branches of science, fluid mechanics did not immediately achieve results that were applicable to real flows when the whole basis of calculus and mechanics was established by Newton (1642–1727). Bernoulli (1700–1782) formulated the importance of fluid pressure, and Euler (1707–1783) laid the foundation of classical hydrodynamics. Other workers such as d'Alembert, Helmholtz, Kelvin, and Rayleigh brought the study of dynamics of an ideal fluid to a remarkable degree of mathematical perfection but without making any immediate contribution to the solution of the many practical problems associated with fluid resistance, flight, or the design of ships.

One of the great puzzles of the eighteenth and nineteenth centuries was d'Alembert's paradox that theoretical calculations of the resistance to fluid motion gave a zero result. One might conclude that the abstract answer was due to the assumption of a perfect fluid. Nevertheless, for air with its extremely small viscosity this appears to be no worse an assumption than that of a rigid body or of a perfect insulator, where realistic results were obtained from the mathematical analysis.

The existence of viscosity is a consequence of the molecular structure of a gas. The molecules of a gas are in incessant random motion, which manifests itself to our macroscopic senses as temperature. Even when the gas has a directed mass flow, the random motion continues. The random motion gives rise to viscosity or internal friction that retards the flow over a body, or alternately, causes the adherence of the fluid to the surface as a body moves along. At the surface it is assumed that there is no slip, and beyond the surface the influence of the body is transmitted by the random motion with decreasing intensity as the distance from the surface increases.

Viscosity itself is not sufficient to account for the large resistance that some body shapes develop while in motion. Without viscosity large forces can be developed by differences in pressure which the fluid exerts on the body. For example, the pressure on the rear of a cylinder in a real flow is far less than the pressure upstream. At the rear of the cylinder the stream lines fail to conform with its shape and separate to form a region of disturbed flow or a wake (Fig. 2).

The problem of separation is of great importance in fluid mechanics. Separation limits the ultimate performance of nearly every piece of turbo machinery from a water tap to a jet engine. The mechanism of separation is today still one of the great problems of fluid mechanics.

The mathematical methods for the treatment of viscous flows were developed relatively early by Navier (1785–1836) and Stokes (1819–1903). The difficulty with the Navier-Stokes equations of motion (Fig. 3) lies in the fact that they are nonlinear and for most boundary conditions are intractable at the present time.

In all practical cases the inertia terms cannot be omitted, and to discard the viscous terms would mean a return to the d'Alembert paradox. An impasse was thus reached, and it was finally resolved by Prandtl (1875–1954) when he formulated his celebrated boundary-layer theory in 1904. The highlights of the theory may be summarized as follows. The boundary layer is extremely thin (Fig. 4). The velocity profile in the

Presented at the CAI-IAS International Meeting, Montreal, Canada, October 14–15, 1954.

* Director and Head of the Department.

boundary layer which starts from zero at the surface (no slip) and reaches the free-stream value at the outer edge is due to viscosity. Outside the boundary layer the flow may be considered as inviscid. The friction force per unit area (shear stress) is the product of the viscosity and the velocity gradient normal to the surface. It is possible, therefore, to develop significant frictional effects despite the low viscosity because the boundary layer is thin and the velocity gradients are large. Using the concept of the boundary layer, Prandtl was able to reduce the complexity of the Navier-Stokes equations and calculated the laminar skin friction experienced by a body.

In the study of the boundary layer it is of the utmost importance to know how air flows past an object. This was accomplished by Reynolds, who in 1883 demonstrated the existence of two basic types of flow: a stable, orderly (laminar) flow and an unstable, chaotic (turbulent) flow (Fig. 5). In addition, Reynolds established one of the most important fundamentals in fluid mechanics when he discovered that the process of transition from laminar to turbulent flow depends on the Reynolds Number ($R = \rho ul/\mu$). It expresses the ratio of the inertia forces to the viscous forces that are prevalent in the flow. The introduction of the Reynolds Number undoubtedly gave order to the mass of accumulated experimental data and facilitated the development of applied aerodynamics.

The problem of turbulence has not been satisfactorily formulated to date so that there is no exact definition of turbulence. Nearly all real flows are turbulent to some extent. By analogy, turbulence may be considered as the macroscopic counterpart of the microscopic random molecular motion, where masses of fluid—called eddies—transport mass, momentum, and energy from one part of the fluid to another. It should be emphasized that whereas the classical hydrodynamical equations can be derived by considering a molecule as a simple elastic sphere, one cannot treat an eddy as a lump of matter with mechanical properties in order to derive some knowledge of turbulence. For this reason, the mathematical theory of turbulence is more difficult and less developed than the corresponding molecular theory. The analogy, therefore, is limited only to a useful illustration.

Since vorticity is generated by viscosity, which is confined virtually to the boundary layer, it may be expected that turbulence will be present in the boundary layer and in its extension to the wake of a body. The flow in a boundary layer may be initially laminar. As the flow progresses along the length of the surface, the critical Reynolds Number is exceeded, and transition to a turbulent boundary layer occurs. The turbulence generates a more "uniform" velocity profile because of the incessant mixing. Immediately in contact with the surface is a relatively thin laminar sublayer in

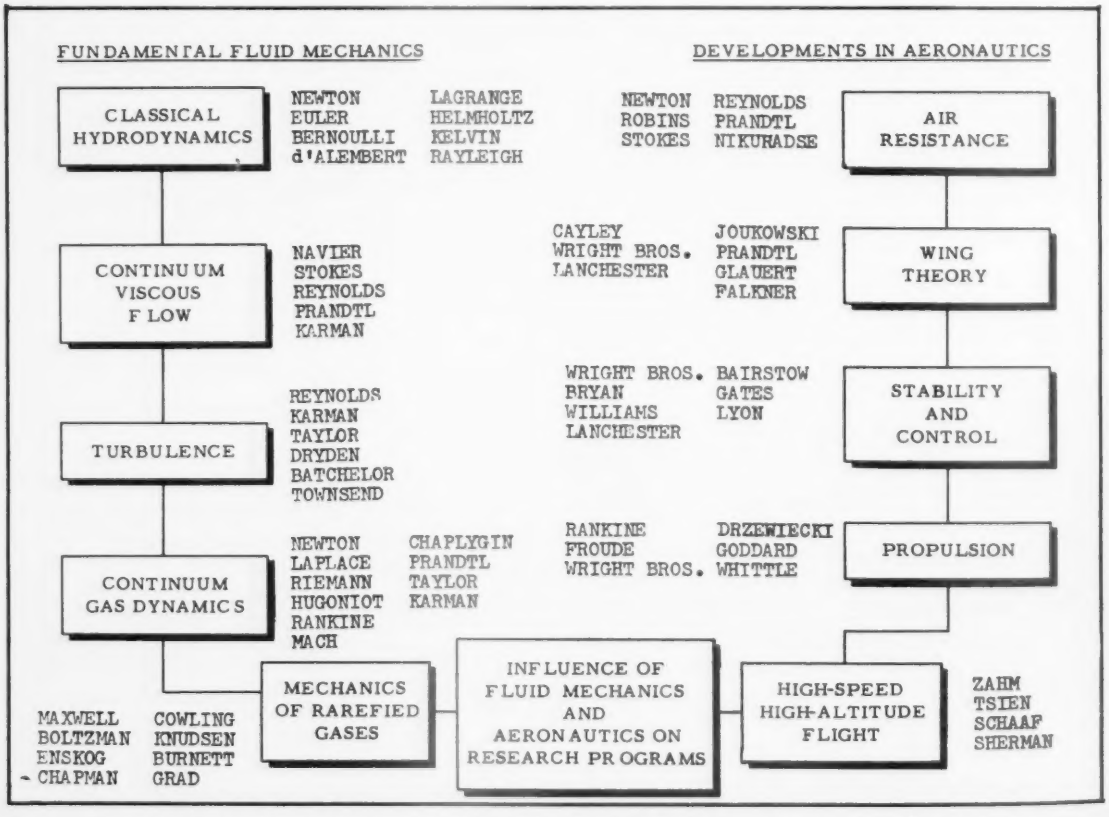


FIG. 1. The role of fluid mechanics in aeronautical development. The list of names is indicative only—it is by no means complete.

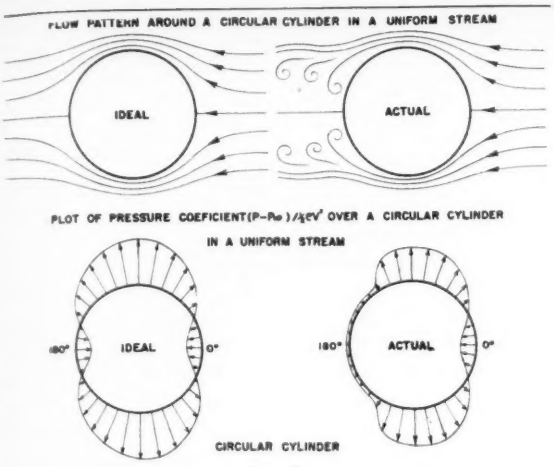
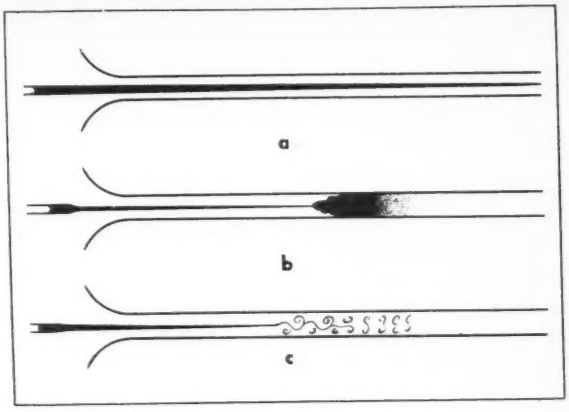


FIG. 2.



REYNOLDS PIPE EXPERIMENTS

FIG. 5.

$$\rho\frac{Du}{Dt}=\rho X+\frac{\partial\tau_{xx}}{\partial x}+\frac{\partial\tau_{yx}}{\partial y}+\frac{\partial\tau_{zx}}{\partial z}$$

$$\rho\frac{Dv}{Dt}=\rho Y+\frac{\partial\tau_{xy}}{\partial x}+\frac{\partial\tau_{yy}}{\partial y}+\frac{\partial\tau_{zy}}{\partial z}$$

$$\rho\frac{Dw}{Dt}=\rho Z+\frac{\partial\tau_{xz}}{\partial x}+\frac{\partial\tau_{yz}}{\partial y}+\frac{\partial\tau_{zz}}{\partial z}$$

where $\frac{D}{Dt}=\frac{\partial}{\partial t}+u\frac{\partial}{\partial x}+v\frac{\partial}{\partial y}+w\frac{\partial}{\partial z}$

$$\tau_{xx}=-p+\lambda\Delta+2\mu\frac{\partial u}{\partial x}$$

$$\tau_{yy}=-p+\lambda\Delta+2\mu\frac{\partial v}{\partial y}$$

$$\tau_{zz}=-p+\lambda\Delta+2\mu\frac{\partial w}{\partial z}$$

$$\Delta=\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}$$

$$\tau_{yz}=\tau_{zy}=\mu\left(\frac{\partial w}{\partial y}+\frac{\partial v}{\partial z}\right)$$

$$\tau_{xz}=\tau_{zx}=\mu\left(\frac{\partial u}{\partial z}+\frac{\partial w}{\partial x}\right)$$

$$\tau_{xy}=\tau_{yx}=\mu\left(\frac{\partial u}{\partial x}+\frac{\partial w}{\partial y}\right)$$

FIG. 3. Conservation of momentum-Navier-Stokes equations.

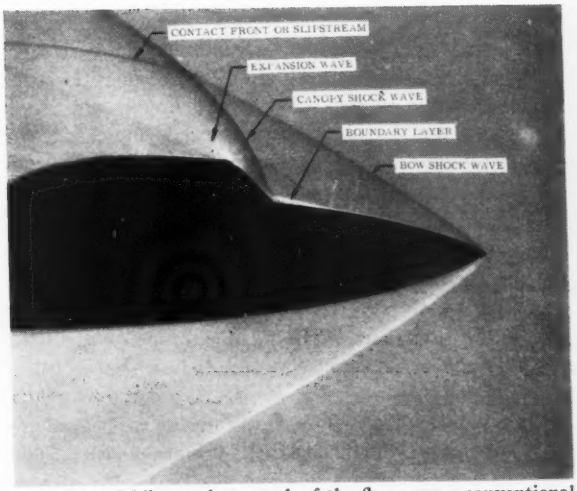


FIG. 6. Schlieren photograph of the flow over a conventional fuselage forebody showing the basic supersonic wave elements, $M = 2.48$.

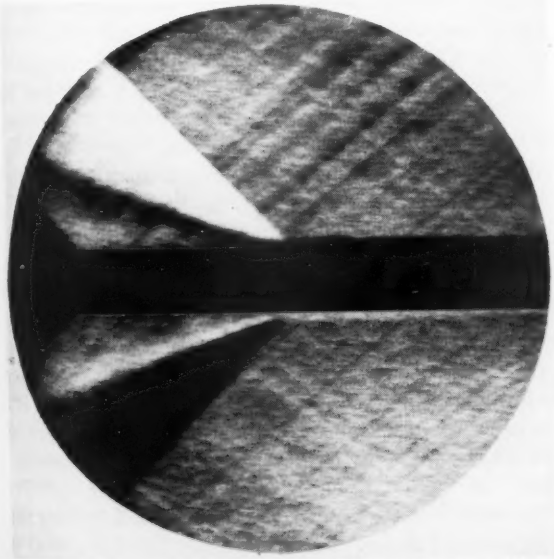


FIG. 4. Schlieren photograph of the flow over a cone-cylinder model showing the boundary layer and its separation, $M = 2.48$.

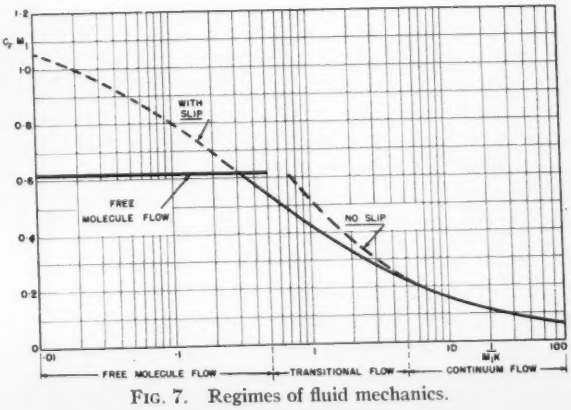


FIG. 7. Regimes of fluid mechanics.

which the velocity gradient is extremely large. If the surface protrusions or irregularities are submerged in the sublayer, then it is said to be aerodynamically smooth; if they are above the sublayer, they increase the surface friction, and the surface is aerodynamically rough. The shallowness of the sublayer means a physically smooth surface as well, and there would be no gain by improving the surface finish if it was already aerodynamically smooth. The skin-friction coefficient is of utmost importance for flight since it determines a sizable portion of the total horsepower required, especially for very high-altitude, high-speed flight. It is desirable then to retain the boundary-layer laminar over as much of the surface as possible in order to reduce the skin-friction coefficient and also, as will be shown later, to minimize the effects of aerodynamic heating at high speed.

At an early stage in the development of aerodynamics, ballisticians observed that air resistance rose sharply when the projectile velocity approached the speed of sound. The interest in high speed was initially confined to ballistics, but with the invention of the turbine it became necessary to study in detail the high-velocity flow of gases through nozzles. In aeronautics, the peculiar effects of high speed were first observed on propellers, and later, as aircraft speeds increased, the entire emphasis shifted to compressible flow.

The novel features of high speed result from the fact that air is compressible—that is, the density of a fluid element is subject to change. The science of gas dynamics treats gaseous flows where density changes are accompanied by velocity changes and thermodynamic effects are prevalent. The idealization of a gas with constant density was for low speeds much more tolerable than that of an inviscid gas. If a gas were really incompressible, then even an infinitesimal pressure pulse would be propagated with infinite speed. Such changes are, in actual fact, propagated with a very high but finite speed, known as the speed of sound. For many low-speed problems the sound speed may be assumed as infinite without great error.

The first calculation of the sound speed was formulated by Newton. He did not realize that the process is so rapid that the heat generated has no time to dissipate—that is, the process is adiabatic. This error was corrected by Laplace (1794–1827). A sound wave is propagated as a cyclic sinusoidal wave consisting of a compression and a rarefaction whose wave lengths lie within certain limits. The pressure rise across sound waves for speech varying from a whisper to normal audibility is about one thousand millionth to one millionth of an atmosphere and is therefore infinitesimal.

As the ratio of the speed of the body to that of sound becomes increasingly greater—that is, the Mach Number (u/a)—the compressibility effects rise, and pressure changes through a disturbance are no longer small. A pressure change of finite amplitude propagates with a Mach Number exceeding one, by an amount that depends on the rise in pressure. Such a pressure disturbance advances as a sharp front, which is called a shock wave (Fig. 6). It is really not a wave in the ordinary sense since it is noncyclic in character. A shock wave is a transition region several molecular mean free paths in thickness, through which the pressure, temperature, density, and entropy rise abruptly and the particle velocity falls sharply.

The properties of shock waves were discussed by mathematicians long before they became prominent in experimental work. Outstanding contributions were made by Riemann (1826–1866), Rankine (1870), Hugoniot (1887), and Rayleigh (1910), and by Prandtl, Taylor, and von Kármán in our own day. Ernst Mach (1838–1916) conducted his memorable researches on choked jets and projectiles, using schlieren photographs, about 15 years before the Wright brothers first flew in 1903. In 1887 he introduced and correctly formulated the Mach cone and Mach angle. The term Mach Number came into general use by about 1939. It is the fundamental parameter for compressible inviscid flow and expresses as a ratio ($M^2 = u^2/a^2$) the kinetic energy of the mass motion of the fluid to that of the kinetic energy of the random molecular (thermal) motion.

In addition to shock waves, supersonic flow is also characterized by isentropic rarefaction and compression waves and contact fronts. The contact front is an extremely thin transition region that grows with time, across which the pressure and velocity* are constant, but the density, temperature, and entropy change sharply. The rarefaction wave is a transition region of finite extent across which the density, pressure, and temperature decrease and the velocity increases, while the opposite occurs for a compression wave. There is no entropy change across an expansion or compression wave. Unlike the d'Alembert paradox for a body immersed in an inviscid incompressible flow, the mathematical analysis shows that a drag does exist in an inviscid compressible flow when the flow has achieved a certain initial Mach Number such that local supersonic velocity is achieved on the body. Such a drag has no counterpart in subsonic flow and is called wave drag. The wave drag experienced by a body arises from the asymmetric pressure distribution generated by the shock and expansion wave system.

An early knowledge of drag came from ballisticians. They demonstrated that there is no difficulty in making a body fly at supersonic speed. The real problem associated with flight is the design of a piloted aircraft that can take off, fly at supersonic speed, and then land safely. Although the drag coefficient curve (C_D) rises with increasing subsonic Mach Number, achieves a maximum in the transonic range ($0.7 < M < 1.2$), and then falls off rapidly in the supersonic regime, nevertheless, the actual drag, which varies as the velocity squared [$D = C_D(\rho/2)\ V^2S$], increases rapidly over the entire speed range. At low altitude the wave drag is

* This is true in one dimension. In two or three dimensions, a discontinuity in tangential velocity can occur.

critical. For example, if a 6-ft. diameter cone-cylinder body would require about 1,000 hp. to fly at a Mach Number of 2 at 100,000 ft., then the power required to fly at the same Mach Number at sea level would be about 100,000 hp.

A more serious problem that exists for supersonic flight arises from aerodynamic heating as the body passes through the air. This phenomenon may be illustrated by considering the inverse problem when the body is at rest and the fluid is streaming past it at a high Mach Number. Where the air is brought to rest the kinetic energy of motion is converted into thermal energy, which is indicated by a rise in temperature. At a stagnation point, such as the nose of an aircraft, the rise over the ambient temperature ($T_0 - T$) is given by (V m.p.h./100)^2 °C. For example, an aircraft flying at about a Mach Number of 4.16 at sea level (3,160 m.p.h.) would experience a temperature rise of 1,000°C. at the nose. Although the aircraft is also enveloped in a boundary layer where the air at the surface is at rest, it achieves a somewhat lower temperature at the wall (T_w). This is due to the fact that the boundary layer is thin, and, despite the fact that the wall temperature tends to be increased by skin friction, it is also decreased by conduction of heat from the surface through the boundary layer to the cool outer stream. The above is expressed by the Prandtl Number ($P_r = \mu C_p/k$), the ratio between the product of the viscosity coefficient and the specific heat at constant pressure and the heat conduction coefficient. For air at standard temperatures this ratio is about 0.72, less than one, which indicates that the heat conduction brings about the lower surface temperature. The ratio of the local temperature rise to that of the stagnation temperature rise is defined as the recovery factor $\theta = (T_w - T)/(T_0 - T)$. It has been found that $\theta = \sqrt{P_r} = 0.85$, for a laminar boundary layer, and $\theta = \sqrt[3]{P_r} = 0.90$, for a turbulent boundary layer. The ratio of the local wall temperature (T_w) to the stagnation temperature (T_0) for a given flight Mach Number (M_1) decreases as the local Mach Number (M) increases. Although some relief in temperature reduction will come about from radiation and from the fact that energy will be partitioned into molecular vibration and dissociation at high temperature, the fact remains that at present materials are not available which can withstand the high temperatures. It appears that some cooling system will be essential to solve this very real and pressing problem. It should be noted that the high temperature that results from the deceleration of the air, coupled with the increase in temperature due to combustion, will limit the operation of a jet engine even further ($M \approx 4$) because of tailpipe and blade failure. Cooling by the use of a refrigeration system alone would bring only temporary relief, but it is not a cure for the heating encountered in a sustained hypersonic or high Mach Number flight. A large mass of coolant would have to be carried and expended. This would be a sizable burden unless the coolant was also utilized for propulsion. At best, refrigeration cooling could be utilized for re-entry into the atmosphere of high-speed, long-range aircraft.

Very high-altitude flight offers the possibility of removing some of the restrictions, such as aerodynamic heating, which are encountered in a denser atmosphere. It also introduces some fresh concepts that were neglected in classical fluid mechanics. At very high altitudes the mean free molecular path (λ) compared to the dimensions of the aircraft (l) is sizable—that is, the Knudsen Number ($K = \lambda/l$) becomes a significant flow parameter. Here, the fluid can no longer be treated as a continuous medium but rather as one composed of discrete particles having ceaseless motion (at sea level $\lambda \approx 2 \times 10^{-7}$ ft. and at 100 miles $\lambda \approx 100$ ft.).

In order to study the phenomena that occur in a rarefied gas, recourse must be made to the kinetic theory of gases. The approach was developed by Maxwell (1831–1879) and Boltzmann (1844–1906). The properties of the flow are described on a statistical basis by considering a definite molecular model and the number of molecules $n(x, y, z, t)$ per unit volume in each macroscopically small element $d\tau$ of physical space and specifying the fraction $f(x, y, z, t, u, v, w)$ of the molecules having velocities in the range (u to $u + du$), (v to $v + dv$), and (w to $w + dw$) of the element $d\omega$ of the velocity space (where $d\omega = du\, dv\, dw$). The distribution function f is of fundamental importance for the determination of the flow properties. Maxwell found the distribution function for a gas at rest. The Maxwell distribution function can be readily generalized for application to a gas in mass motion.

There are two principal equations that govern molecular motions. They are known as Boltzmann's equation and Maxwell's transfer equation. Consider the space element $d\tau$ that possesses molecules in the entire range of the velocity space. Boltzmann's equation formulates that the rate at which a number of molecules having a certain range in the velocity space (called class 1 molecules) increases in an element $d\tau$ of the physical space is equal to the rate of flux of class 1 molecules through the sides of $d\tau$ plus the rate of gain of class 1 molecules from other classes due to intermolecular collisions. Similarly, Maxwell's transfer equation states that the rate of change of any quantity $Q(u, v, w)$ transported by the molecules in an element of volume $d\tau$ is equal to the rate of flux of Q in through the sides of $d\tau$ plus the rate of gain in Q due to intermolecular collisions. To obtain the equations of motion the velocity distribution function is found by solving Boltzmann's equation, which in turn is inserted into Maxwell's transfer equation, using Q to represent mass (m), momentum (mV), and energy [$1/2(mV^2)$]. When the Maxwell distribution function is inserted, then the corresponding equations of motion are those for the isentropic flow of an ideal gas.

A general method for obtaining the equations of motion for a gas including viscosity and heat conduction was developed by Enskog (1917). His work was extended by Chapman and Cowling, Burnett, and Grad. In the Enskog-Chapman method, a velocity distribution

function is assumed which is a series perturbation of the Maxwellian velocity distribution—that is, $f = f_0(1 + \epsilon + \epsilon^2 + \epsilon^3 + \ldots)$, where f_0 is the Maxwellian distribution and ϵ is a correction depending on the mean free path and other factors. By retaining the ϵ term, Enskog derived the Navier-Stokes equations. Burnett obtained the second-order solution by retaining ϵ^2, which is valid for slip flow—that is, where a tangential velocity component exists at the surface. It contains terms whose order depends on the product of the Mach and Knudsen Numbers. The equations of motion including the third-order terms have recently been solved by Grad. It is not evident, *a priori*, that these solutions represent real flows, and this matter is presently under experimental investigation. It should be noted that an additional advantage of the kinetic theory approach is that it also yields the boundary conditions and expressions for the heat conduction and viscosity coefficients. The degree to which the results represent real flows depends on the accuracy of the molecular model and the velocity distribution function.

The earliest experiments with rarefied gases were made by Kundt and Warburg (1875), who measured the flow rate of gases through pipes. They found that at low densities the mass flow exceeded that predicted by continuum theory (Poiseuille flow). This effect was attributed to "slip flow"—i.e., it was postulated that a finite gas velocity existed at the surface of the tube.

A more thorough investigation of this phenomenon was made by Knudsen in 1909. He showed that the mass flow at low speed was a function of the ratio of the mean free path to the pipe diameter—that is, the Knudsen Number ($K = \lambda/D$). On the basis of laminar pipe flow results, low-speed gas dynamics may be subdivided according to the Knudsen Number into the following somewhat arbitrary flow regimes: continuum flow ($K < 0.01$), slip flow ($0.01 < K < 0.1$), transitional flow ($0.1 < K < 10$), and free-molecule flow ($K > 10$). Thus an aircraft flying at a very high altitude would pass through all the regimes of fluid mechanics during the course of its flight from take-off to cruising.

For slip flow the velocity and temperature discontinuities at the surface depend on the product of the Mach and Knudsen Numbers. The discontinuities may be assumed as zero for low-speed work where K and M are small. An important aspect of high-speed slip flow is the reduction of the skin friction due to slip. The equations for the boundary conditions are derived from a consideration of the molecular interaction with a surface. A molecule may be reflected as an elastic rebound (specular reflection), or it may be trapped at the surface and re-emitted in a random direction (diffuse reflection). Since any real surface is microscopically quite rough, the molecular reflections tend to be diffuse. This has been verified experimentally by Knudsen and Millikan. Molecular collision with a surface also results in an adjustment of the average energy level of the molecules to that of the surface. Knudsen expresses the degree of this adjustment in the form of an accommodation coefficient $\alpha = (E_i - E_r) \div (E_i - E_w)$. The subscripts i, r, and w refer to incident, reflected, and wall conditions respectively. E_w is defined as the energy that would be carried by the reflected molecules if they were streaming from a gas in equilibrium at the wall temperature. Wiedmann has redetermined recently that the accommodation coefficient is near one and depends on the type of metal and not on the surface finish. In the case of free-molecule flow, where the mean free path is large compared with the body dimensions, the boundary conditions and flow properties lend themselves to a simplified analysis. Here it is assumed that the motions of the incident molecules are not affected by collisions with reflected molecules. Such collisions may in fact occur, but since they are far away from the body their influence is negligible. Knudsen applied the free-molecule theory to mass-flow measurements of highly rarefied gases in pipes. Epstein deduced the drag of a sphere in free-molecule flow and found it to be in good agreement with some of the oil-drop measurements made by Millikan.

The rapid development in free-molecule flow studies since 1944 is due largely to the researches, in supersonic low-density wind tunnels, by Schaaf, Kane, Folsom, Sherman, et al. (University of California) and Stadler, Goodwin, Creager, et al. (NACA). The first experimental verification of high Mach Number, free-molecule flow was obtained in 1950 (NACA). Good agreement was found between the calculated and measured values of drag and heat transfer for a cylinder mounted transverse to the stream, over a range of Knudsen Numbers between 4 and 185 at molecular speed ratios (S) up to 2.3 (Fig. 7). For free-molecule flow work the speed ratio $S = U/C_m$ is in common use, where U is the free-stream mass velocity and C_m is the most probable molecular speed. S is related to the Mach Number through the sound speed—i.e., $S = M\sqrt{\gamma/2}$.

Several aspects of free-molecule flow are worth noting. The drag depends considerably on the heat transfer and arises from the fact that the momentum imparted by the reflected molecules depends on the surface temperature. The adiabatic temperature recovery factor may exceed one. It was shown previously that in continuum flow the recovery factor is always less than one, in air, for a real flow. If the Prandtl Number is greater than one it is theoretically possible for the recovery factor to exceed one in a continuum flow. However, the Prandtl Number $P_r = \mu C_p/k$ has no significance in free-molecule flow because the temperature and velocity gradients which are necessary for the existence of k and μ are absent. The above serves to illustrate some of the fundamental differences between continuum and free-molecule flow.

(II) Applications to Aeronautics

The Problem of Mechanical Flight

From the earliest times of which we have any records, man has enviously observed the birds and desired for

himself the freedom to soar above the earth. The record of these hopes and dreams can be found in ancient mythology (Icarus and Daedalus), scriptures, sculpture, and painting. As in other areas of living, man was unable to achieve this goal merely by wishing and hoping for it. Many centuries passed before the problem of mechanical flight was even stated, let alone solved. In 1809, Sir George Cayley defined it as the problem of making a surface support a weight by the application of power to the resistance of the air. This is a remarkable definition for its time but is somewhat lacking in detail. In modern language, and with the hindsight that always makes things look so easy, we may subdivide the whole problem under the following headings: Lift, or wing theory; Resistance, or drag; Propulsion; and Stability and Control.

The successful achievement of flight, involving an understanding of each of the above elements, was not possible until a certain stage of development had been reached in science and in engineering. Thus no flight at all was possible until the rudiments of lift, resistance, and stability had been dimly conceived, and no powered flight was possible before the advent of a light powerful engine.

The branches of physics which dominate the scientific prerequisites of flight are solid and fluid mechanics. In the following remarks, the subproblems of flight will be discussed in relation to fluid mechanics.

The Problem of Resistance

The earliest practical problems involving fluid motion concerned the resistance offered by the fluid to bodies moving through it and the resistance to flow in pipes and channels. These arose in connection with sailing, gunnery, and hydraulic works. In attempting to find answers to questions of fluid resistance, the classical hydrodynamics of ideal fluids led only to d'Alembert's paradox, previously mentioned—namely, that the resistance is zero. D'Alembert refers to this result as "a singular paradox which I leave to geometricians to explain"; and Lord Rayleigh, a century later, had this to say: "On this theory the screw of a submerged boat would be useless, but, on the other hand, its services would not be needed."

The reason for the failure of the ideal fluid theories to predict resistance is a subtle one. It may be summed up as follows: In this theory the admittedly very small viscosity of the air is neglected on the assumption that small viscosity will make only a small difference in the solutions. Actually, however, when a solution to a viscous flow problem is found, and the viscosity is then permitted to approach zero, the solution does not tend to that for an ideal fluid but rather to the very high Reynold's Number case. It remains different in character, always containing a significant drag. Thus the viscous terms must be introduced into the differential equation right from the first.

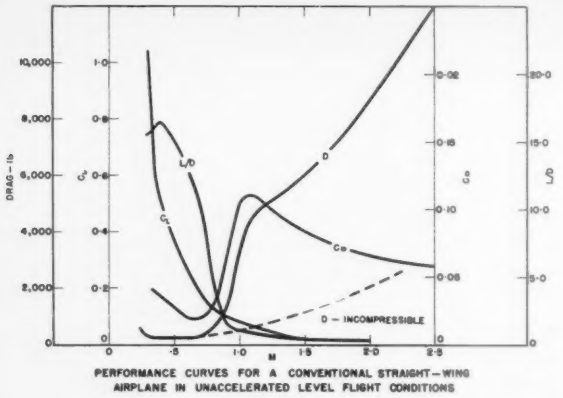
Newton, as early as 1687, conducted experiments on the drag of spheres at low speeds and from these verified the speed-squared law, which he had deduced on theoretical grounds. Later, Robins extended the data to higher speeds and showed that the drag was considerably more than would be obtained by the speed-squared law. His experiments were carried out using a ballistic pendulum and included speeds up to supersonic.

Not until the Navier-Stokes equations were formulated was any progress possible in the calculation of drags. Even then, this progress was slow, for the difficulties inherent in these nonlinear partial differential equations have precluded general solutions even to this day. Some special solutions were obtained, however. Stokes solved the equations approximately to obtain the law of resistance for spheres at very low speeds, and the simple cases of laminar flow through circular pipes and between parallel infinite walls have been solved.

Even if we had complete solutions of the Navier-Stokes equations, they would supply only a small part of the story of drag, since in themselves they cannot give any intimation of the character of turbulent flow. The significance of turbulence as a factor in resistance was not recognized until Reynolds' famous experiments showed that the resistance is much higher in turbulent pipe flow than in laminar. Later, the extensive measurements by Nikuradse established the basis for a semiempirical theory of turbulent flow in pipes and boundary layers.

A real understanding of drag came only with Prandtl's boundary-layer theory, which illuminated the nature and magnitude of skin friction and the basic mechanism of separation. It laid the basis for a correct prediction on purely theoretical grounds of the skin friction and separation point in laminary boundary layers. The outstanding problems yet to be solved in this connection are the prediction of these same characteristics for a turbulent boundary layer and the prediction of the transition from laminar to turbulent flow. Until these problems are solved, the prediction of drag will remain on an experimental empirical basis. In all cases where a body moving at constant velocity V experiences a drag D, the propulsive system expends energy at the rate DV. This energy must appear, in one form or another, in the air mass through which the body moves. In the case of skin friction and wake drag which are directly dependent on viscosity, this energy first appears as kinetic energy of the air and later, when the body has long since passed, is turned into heat by viscous dissipation. This drag is furthermore directly associated with the increase in entropy of the air and can be calculated from it.

Apart from skin friction and wake drag, which exist as a result of viscous dissipation and are so dependent on the boundary layer, there are two other kinds of resistance, distinctly different from these—and from each other—in their physical and mathematical characteristics. The first of these, the induced drag of a finite lifting surface, can exist in an inviscid incompressible fluid. It results from the kinetic energy left behind the wing in the wing-tip vortices, which in an inviscid fluid would extend to infinity behind the wing. This drag



PERFORMANCE CURVES FOR A CONVENTIONAL STRAIGHT-WING AIRPLANE IN UNACCELERATED LEVEL FLIGHT CONDITIONS

FIG. 8.

can be calculated on the basis of classical hydrodynamics. The second is a drag component present at supersonic speeds and known as wave drag. This component is also essentially independent of viscosity in that it can occur in an inviscid fluid and can be calculated from the theory of a continuous compressible fluid (Fig. 8).

It was stated above that induced drag and wave drag are essentially independent of viscosity, since they both can exist in a frictionless fluid. In real fluids, however, the vortex system and the wave configuration both are influenced, sometimes decisively, by the boundary layer. Thus the induced drag and wave drag are indirectly influenced by viscosity. This fact emphasizes again the importance of attaining an understanding of the turbulent boundary layer comparable to that we have achieved of the laminar layer.

The Development of Wing Theory

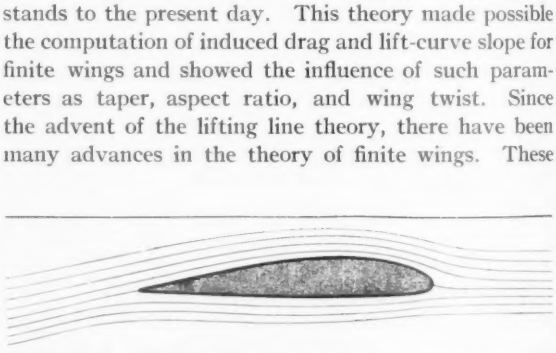
One of the striking facts of aerodynamics is that most wing theory derives directly from the dynamics of ideal fluids, incompressible and compressible. The role of viscosity enters in one important particular only—namely, the justification on physical grounds of the Kutta condition, or Joukowski hypothesis, which requires that there shall be no flow around the trailing edge. This condition is applied to render unique the solutions to ideal fluid flows about both two-dimensional and finite wings (Fig. 9).

The first calculation of the lift of an inclined plane was carried out by Newton, who postulated a rarefied frictionless fluid. His result that the lift is proportional to the square of the sine of the angle of attack was numerically much too low for wings in air and is said to have discouraged subsequent workers from attempting to solve the mystery of flight. Actually, the key to the mystery could have been found in another paper of Newton's, in which he first recorded the Magnus effect, rediscovered by Magnus two centuries later. In this phenomenon, we find the action of circulation around a body immersed in a stream giving rise to a large force perpendicular to the stream.

The precise formulation of the associated law under two-dimensional conditions at incompressible speeds was effected by Kutta and by Joukowski independently and is now known as the Kutta-Joukowski theorem. When combined with the Kutta condition previously mentioned, the way was opened to great advances in the theory of airfoil sections. The long known and highly developed techniques of classical hydrodynamics and applied mathematics were brought to bear on the problem and resulted in the development of many series of airfoil sections, bearing the names of Joukowski, Carafoli, von Kármán, Trefftz, and von Mises. Other developments in the theory of thin airfoils led to methods for solving the two related problems: (1) Find the pressure distribution around a given arbitrary profile, and (2) Find the profile shape that has a given arbitrary pressure distribution. The solution of the second, so-called inverse problem was of great importance in connection with the development of low-drag and high-speed airfoil sections, both of which require special characteristics in their pressure distribution, although for different reasons.

In general, the ideal fluid theory of airfoil sections is quite well substantiated by experiment. In particular, such quantities as lift-curve slope, moment coefficient, and aerodynamic center location are reasonably well in accord with experiment. The theories have also been useful but not so successful in predicting the influence of control flap deflections. The hinge moments especially are much affected by the boundary layer near the rear of the airfoil, and considerable differences are found between theory and experiment.

Although the theories and methods referred to above sufficed for investigations of airfoil section profiles, the problem of the finite wing as a whole had to be solved. The first step was achieved by Lanchester, who postulated the vortex system of the wing. This concept was elaborated upon by Prandtl, who produced the lifting line theory for high aspect ratio unswept wings which stands to the present day. This theory made possible the computation of induced drag and lift-curve slope for finite wings and showed the influence of such parameters as taper, aspect ratio, and wing twist. Since the advent of the lifting line theory, there have been many advances in the theory of finite wings. These



FLOW ABOUT AN AIRFOIL IN CONFORMATION WITH KUTTA-JOUKOWSKI HYPOTHESIS

ACTUAL PRESSURE DISTRIBUTION ON AN AIRFOIL

FIG. 9. Joukowski airfoil.

have been based not on more knowledge of fluid mechanics but rather on the development of suitable mathematical techniques. These advances have been concerned with low aspect ratio wings, sweptback wings, and delta wings. Falkner, Weissinger, Multhopp, R. T. Jones, and Lawrence are among those who have made significant contributions in this area.

Simultaneous with this progress, there emerged the theories of oscillating airfoils, primarily for use in flutter analysis. Chief among the contributors in this field are Theodorsen and Garrick. Again the theoretical foundation lay in the classical hydrodynamics. The difficulties that had to be overcome in order to achieve useful results were primarily on the mathematical side.

In spite of all the development in subsonic wing theory, there is still much to be done. A problem of considerable importance for modern airplanes is aeroelastics, both static and dynamic. The computation of wing characteristics for analyses in this area requires the ability to predict the surface loading for arbitrary angle of attack distribution, both statically and when the wing is oscillating. This can now be done only for certain particular surface shapes, the delta wing of moderate aspect ratio *not* being among them.

The extension of the incompressible airfoil theories to higher subsonic Mach Numbers was effected by the application of linearized compressible flow theory. The first step, taken independently by Prandtl and Glauert, resulted in the Prandtl-Glauert correction, later improved by von Kármán and Tsien. When applied to incompressible wing solutions this enabled the results to be carried up to quite high Mach Numbers of the order of 0.6 to 0.7.

A significant theory, in the light of modern design problems, was that given by R. T. Jones in 1946 concerning the lift distribution on very slender pointed wings. This theory showed that the lifting characteristics of such bodies are the same at subsonic, transonic, and supersonic speeds. It is interesting to note that Jones did not draw his curve right through $M = 1$, but subsequent developments of slender body theory, and experimental evidence, show that he would have been correct in doing so.

The theory of supersonic airfoils begins with Ackeret, who in 1925 gave the linear theory of the lift, drag, pitching moment, and pressure distribution of two-dimensional airfoils in supersonic flow. It is a remarkable fact that this theory is much simpler than its subsonic counterpart and permits the solution of both the direct and inverse problems with less mathematical difficulty than is encountered in subsonic flow.

The extension of linearized supersonic wing theory to finite wings has also been an easier task than the corresponding subsonic one. What makes the problem easier in the supersonic case is that, for both subsonic and supersonic leading edges, the problem can be reduced to quadrature, involving integration of functions of the wing geometry in a finite region upstream of the point where the pressure is to be found. There now exists a method of calculating in a straightforward manner the distribution of loading over a supersonic wing with subsonic leading edges and arbitrary surface warping. In principle the same thing is possible when the leading edges are supersonic. This cannot be said of the state of the art for wings at subsonic speeds. In this respect, supersonic wing theory is more advanced than the subsonic theory. From those who contributed to these developments we may single out for mention Stewart and Robinson, who independently obtained the exact solution of the delta wing with subsonic leading edges, and Evvard, who gave a consistent theory applying to both subsonic and supersonic leading edges.

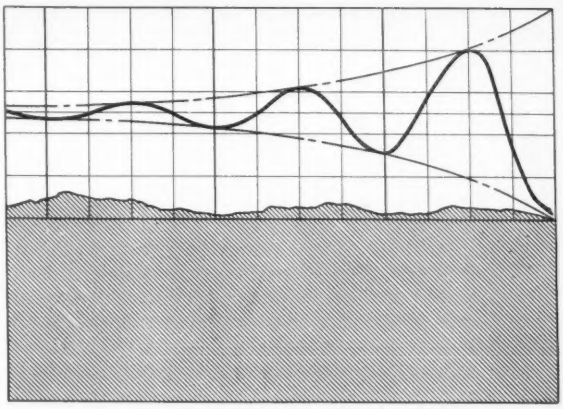


FIG. 10. Dynamic longitudinal instability.

Stability and Control

The difficulties involved in making their flying machines stable and controllable were the most trying encountered by the pioneers of flying (Fig. 10). Stability was achieved in flying models long before any human flights were made. The principle of static stability seems to have been understood quite early, perhaps as far back as Sir George Cayley (1773–1857), who, incidentally, was the first to introduce dihedral in the wings. It was the control of the airplane that proved to be so stubborn a problem. Methods of control progressed from Lilienthal's crude solution of moving his weight about to the refined solution of the Wright brothers, who introduced independent control of rotation about each of three airplane axes by aerodynamic means. It was in this connection that the achievement of the Wright brothers was perhaps most noteworthy.

This branch of aeronautics is founded upon a tripod of equally important disciplines—fluid mechanics, solid mechanics, and applied mathematics. In assessing the problems of stability and control and their relation to fluid mechanics, we find that the situation is similar to that which occurs in wing theory—that is to say, ideal fluid theory provides the basic fluid mechanics for much of the theoretical analysis. The failure of this theory, previously mentioned, to give reliable quantitative information on the effectiveness and hinge moments of controls has made it necessary

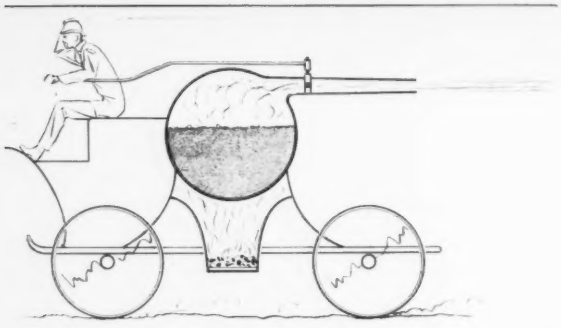


FIG. 11. Propulsion.

to rely almost exclusively on experimental data for such information. In discussing wing theory above, no special mention was made of the specific kinds of problems that have to be solved in relation to stability and control. In the first place, for this purpose, we usually need to know only the resultant forces and moments which act on the wing, their distribution being rather inconsequential. However, we need to know these forces and moments not only when the wing is in straight flight but also when it has superimposed on straight flight small angular velocities in roll, pitch, and yaw. We require also to know these forces when the airplane is in curved flight, is flying with oscillatory motions, and when the controls are deflected.

A feature of the flow past wings which is not of much intrinsic interest relative to wing theory but is a vital factor for airplanes with tails is the downwash in the wake. The prediction of the downwash at the tail is required with the usual engineering precision for the proper design of the tail. Such predictions can be made, for both subsonic and supersonic wings, utilizing the ideal fluid theory.

Although Lanchester wrote a paper on the dynamic stability of airplanes before the Wrights flew, still most of the analysis done on airplanes for the first two or three decades of flight was what we call static stability and control. In that subject, attention is fixed on the equilibrium states of the airplane. The stability of these states with respect to rotational disturbances is studied, as is the effectiveness of the controls in changing them. Such studies, although indispensable, were found to yield only part of the story. It has now become quite common to carry out extensive analyses of the dynamics of the disturbed motions of airplanes. Such studies provide an appreciation of the flying and handling qualities of an airplane and also supply much extremely important information on the air-load distribution in maneuvers and rough air. The considerable amount of calculation involved in such analyses has led, in recent years, to the widespread use of computing machinery, mainly analog computers on which the differential equations of the airplane can be closely simulated.

The most serious of the problems encountered by airplanes when the transonic range was entered was one of stability. Straight wings of high aspect ratio have their aerodynamic center at about $^1/_4$ chord point in subsonic flight and the $^1/_2$ chord point in supersonic flight. The consequent large rearward movement of the aerodynamic center on passing through the transonic range introduces strong diving moments. This, coupled with a deterioration in elevator effectiveness, leads to uncontrolled dives. The introduction of highly sweptback wings, first recommended by Busemann in 1935, delays the onset of this phenomenon to higher speeds. The ideal solution, of course, is to find a wing shape such that the center of pressure is in the same location in both subsonic and supersonic flight. Jones's theory, mentioned before, shows that this is the case for slender pointed wings. Thus the low aspect ratio delta wing appears to be the answer for transonic flight. Although such aircraft, either with or without tails, have introduced new problems in the low speed range, nevertheless, one can say with confidence that this kind of configuration produces an airplane that can land and take off at low speeds and fly with good handling characteristics right through to supersonic speeds.

The high speed and large size of modern airplanes make the task of flying them virtually impossible for a human pilot without any mechanical aids. The use of powered control systems and automatic pilots has now become widespread. The automatic devices (servomechanisms) can be used even to produce synthetic stability when the airplane with free controls would be unstable. The development of such systems has required, in addition to the solution of difficult electromechanical problems, a detailed knowledge of the stability derivatives of new and unconventional configurations in both low-speed and supersonic flight. The work of acquiring such information is proceeding at the present time.

Propulsion

All means of aircraft propulsion (propellers, jets, and rockets) ultimately involve the principle of reaction to an accelerated jet stream (Fig. 11). This principle was exemplified as early as 360 B.C. by the philosopher Archytas, and we have in Hero's engine (300 B.C.) the rudiments of a reaction steam turbine.

At about the same time, a suspended rocket using steam is recorded to have been employed as a propulsion source for a mechanical flying bird.

A Chinese invention of the thirteenth century, used for military purposes, is the powder rocket. This represented an important step toward the efficient controlled use of the reaction principle. Later, about 1500, it is recorded that an attempt was made to utilize a rocket to propel a man-carrying flying machine.

In Europe's military history rockets made several sporadic and generally short-lived appearances. Their first effective application was in the mass bombardment (25,000 rockets) of Copenhagen in 1807. Because of their inferior accuracy rockets were afterward abandoned for military use in favor of rifled weapons. It was not until 1903 that a Russian (K. Ziolkowsky) perceived in the rocket a method of propulsion able to

function in the vacuum of space. But it was not until after 1920 that the development of the rocket as we know it today was started.

Although there was such a long history of rocket development, mechanical flight came only after the development of the internal combustion engine.

The basis of modern reciprocating gasoline engines is to be credited to Lenoir, Otto, and Langen between 1860 and 1880. Otto developed the four-stroke cycle engine with ignition, and in 1892 Diesel invented what is known today as the diesel engine.

Both types of engines were still in their infancy when, in 1895, Sir Hiram Maxim, who lost a fortune in building a primitive restrained airplane equipped with a 360-hp. steam engine, advised young engineers "to turn their thoughts in the direction of the petroleum motor." But no gasoline engine powerful and light enough was on the market even in 1903 for use as an airplane propulsion device.

The Wright brothers had to build their own engines. The first one, a four-cylinder motor of about 170 lbs., delivered 12 hp. It was this engine that powered the first famous flight of 852 ft. in 59 sec.

The success of the first mechanical flight was as much dependent on the propeller as it was on the airplane's frame or engine, and the propeller as well had to be designed by the Wrights. As they found that no theory for marine propellers was available, they based their design on the idea "that a propeller is simply an airfoil traveling on a spiral course." Using airfoil sections and appropriately twisting the blades, they succeeded in building propellers of remarkably high efficiencies which undoubtedly helped to make their first low powered flight a success.

Contributions to propeller theory were made by Rankine (1865), who presented the momentum theory, and Froude (1878), who developed the blade element theory. This theory was later refined and advanced by Drzewiecki (1892). The vortex wing theory of Lanchester and Prandtl was later applied to propellers by Betz, Glauert, Pistolesi, and von Kármán. Although the early contributions of Rankine and Froude were highly significant, they were of little use to the Wright brothers in solving their design problems.

Today the propeller has reached its economic upper limit. With airplane speeds of 500–600 m.p.h. the propeller tips are apt to reach the speed of sound where flow separation and compressibility effects reduce its efficiency so much as to prevent any significant increase in aircraft speed even when the power is still available. Variable propeller pitch, counterrotating three- and four-blade propellers, etc., could not solve this problem. It was soon realized that supersonic level flight is difficult to achieve economically with a propeller-driven airplane. A further limitation on supersonic flight was the piston engine, since it is practically impossible to construct such engines for aircraft in excess of 4,000 hp.

This state of affairs led to the adoption of a new engine type, the gas-turbine jet engine, and its simplified versions, the ram-jet and the pulse-jet. The rocket came to life again as an aircraft propulsion device, used for take-off assistance, missiles, and high-altitude supersonic rocket aircraft.

This group of modern propulsion devices can be classified as duct engines. Their efficiency increases with the pressure in the combustion chamber. If the front end of the duct is open (which is not the case with rockets), the stagnation pressure of the inflow air could be used to run the duct, but speeds of about 500 m.p.h. are necessary for this purpose (ram-jets or aerothermodynamic ducts). But the pressure in the combustion chambers may be increased to advantage independently of the forward speed by the use of a compressor. This compressor may be driven by a turbine on the same shaft (Whittle's patent, 1932) or by an independent reciprocating engine. The first jet engine of the Whittle type with a centrifugal compressor was flown on August 27, 1939, in a Heinkel He 178, whereas the duct-engine combination, the Caproni Campini, flew exactly 1 year later. Since then, the jet engine has been developed into a propulsion source of incredible power, delivering up to 10,000 lbs. of thrust. Such thrusts have made possible the attainment of supersonic speeds on operational aircraft.

There is an operational limit on jet engines which occurs at very high speeds. This is reached as soon as the stagnation temperature of the inlet air, in combination with combustion, produces such high temperatures that the turbine blades and ducting fail. This limitation occurs at about $M = 4$.

To overcome the temperature problem it will be necessary to fly aircraft at extremely high altitudes (400,000 ft.). At this height, there is insufficient aerodynamic lift, a difficulty that may be overcome by flying at hypersonic speeds. (This will be clarified in the next section.) Only the rocket engine can make such flights possible. These have recently been developed to a high efficiency, owing primarily to the introduction of liquid fuel propellants.

High-Speed, High-Altitude Flight

One of the principal aims of the aircraft designer is the attainment of greater speed. For a constant drag coefficient the propulsive power varies as the cube of the speed. The rise in flight speed followed in fact the development of more powerful piston engines. For example, in the period of 1917 to 1930 aircraft speeds doubled from 100 to 200 m.p.h. because of an eightfold increase in engine power from 100 to 800 hp. By 1930 it was realized that a further doubling of speed through an increase of power alone was not feasible since it would require a piston engine of 6,000 hp. Attention was then directed to reducing form drag through streamlining and fairings, and a further rise in speed to 400 m.p.h. was achieved.

During the second world war and particularly after the development of the turbojet, aircraft speeds rose to a point where compressibility effects became predominant. Entry into the transonic regime was first

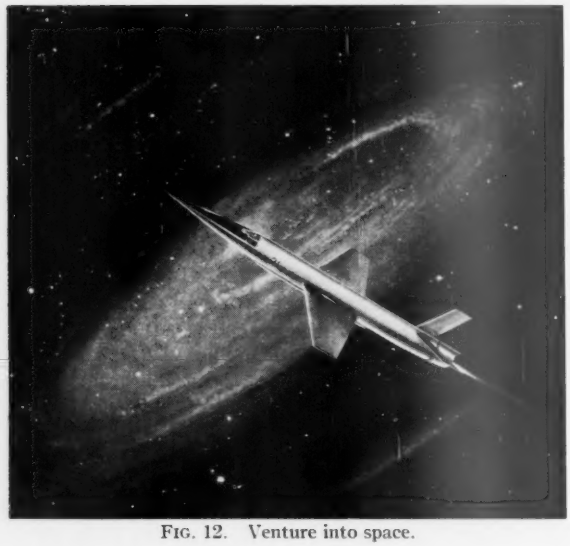


FIG. 12. Venture into space.

encountered in high-speed dives. Local shock waves on wings caused boundary-layer separation, which resulted in the "shock stall" with its accompanying loss of lift, large drag rise, and instability in the form of buffeting. Since transonic flow is a mixed flow regime it is more difficult to analyze than either entirely subsonic or supersonic flow. Even wind-tunnel investigations of transonic flow have lagged several years behind supersonic flow studies due to "choking" conditions near sonic speeds.

Simultaneously with the study of transonic speeds, extensive work has been done at supersonic and hypersonic speeds as a result of various guided-missile programs. The development of a really large rocket motor made it possible for the V-2 to travel at supersonic speeds. Today the ram-jet holds promise for sustained long-range flight at moderate altitudes, particularly since the specific fuel consumption decreases at high speeds when it approaches that of a turbojet for Mach Numbers between 2 and 3. As was noted above, the present limitation to hypersonic flight is the real problem of aerodynamic heating at moderate altitudes.

One way of avoiding this difficulty is to attain very high altitude flight. Historically, the attainment of high-altitude flight was marked by two sudden advances. In the early thirties superchargers and oxygen equipment were perfected and pushed the ceiling to over 50,000 ft. In the mid-forties rocket aircraft were finally realized, and a record altitude of 85,000 ft. was attained, where 97 per cent of the atmospheric mass is already below the pilot. Aircraft at these altitudes may rightly be said to operate in an area between atmosphere and space.

The application of the mechanics of rarefied gases to aircraft has resulted in a branch of aeronautics which was named "superaerodynamics" by Zahm (1934). Some interesting results may be obtained from free-molecule flow theory. For instance, the aerodynamic forces are negligible. At an altitude of 100 miles, where the molecular mean free path is about 100 ft., the density ratio referred to sea level is only about 7×10^{-8}. The lift coefficient of a flat plate at an angle of attack of 20° in free-molecule flow at a Mach Number of 30 is 0.05. The lift then is about 0.0045 lb. per sq. ft. The wing itself is extremely inefficient under these conditions, and the lift to drag ratio of 0.068 for a flat plate is characteristic of free-molecule flow. At very high speeds the thermal velocities of the molecules are negligible compared to the velocity of mass motion, so that the forces on a plate may be computed by assuming that the molecules travel in straight lines until they strike the plate. Newton performed such a calculation, assuming specular reflection. As was noted above, he obtained such a low value of the lift to drag ratio that he concluded flight was impossible.

The aerodynamic heating problem is less serious at high altitudes because of the fact that the air is so rarefied that a much smaller amount of heat is transferred to the body by molecular or forced convection. The temperatures of a flat plate traveling at 36,000 ft. per sec. at altitudes between 75 and 190 miles have been computed by Stalder and Zukoff for a free-molecule flow. They found that aerodynamic heating is negligibly small at altitudes above 125 miles. At altitudes above 150 miles, solar radiation plays the dominant role in determining surface temperatures. It is important to keep the angle of attack low. For example, at 75 miles, a surface with an emissivity of one would attain a temperature of 900°F. at zero angle of attack, and 2,600°F. at an angle of 90° at a speed of 36,000 ft. per sec. The effects of surface emissivity and accommodation coefficient are not as telling on surface temperature as the variation in angle of attack.

It appears that the atmospheric regions between 100,000 and 400,000 ft. are unsuitable for sustained flight. For example, at 200,000 ft., the density of the air is over 3,000 times less than at sea level, so that by present wing loading standards the aircraft must fly at $M = 10$ to sustain itself. However, the maximum permissible speed, considering aerodynamic heating at this altitude, would be about $M = 4$. These conflicting demands are resolved at about 400,000 ft. where even a speed of $M = 24$ would not present a danger to the aircraft. At this speed aerodynamic lift is no longer necessary, since the aircraft would maintain a path of constant altitude—that is, a circular orbit, under the influence of the centripetal force of gravity alone (Fig. 12).

Thus high-speed, high-altitude flight is man's last step before venturing into space.

(III) The Role of Fluid Mechanics in Research Programs

In the preceding discussion we have seen that new achievements in fluid mechanics have been accompanied by corresponding advances in airplane design. As the motion of gases is more completely understood, the design of aircraft with improved performance be-

comes possible. Future long-range trends in aerodynamic design will be the result of current fundamental research in fluid mechanics.

Modern research programs reflect this point of view. Although large sums of money are spent on developmental work aimed at immediate improvements in design, efforts are also made to maintain a reasonable division between development and fundamental research. It is indicative that the frontiers of modern studies of the motion of gases now lie in the realms of the mechanics of rarefied gases and the dynamics and thermodynamics of high Mach Number flows which are closely related to the problems of high-speed flight at high altitude.

Current programs of basic research in fluid mechanics may be illustrated by the work at the Institute of Aerophysics. Two intermittent supersonic wind tunnels, which operate between a dry-air storage room at atmosphere pressure and a vacuum sphere of 40-ft. diameter, are used for investigations of the properties of boundary layers at Mach Numbers up to 5 or 6, with emphasis on low-density flows. In particular, the effects of large temperature and pressure gradients on laminar and turbulent boundary layers are under study. These two wind tunnels will be supplemented by a continuous operating tunnel now under construction which will provide for tests at Mach Numbers of 3 or 4 in highly rarefied gases down to and including slip flow and free-molecule flow.

The rapid increase in aerodynamic noise associated with recent improvements in the performance of jet aircraft has necessitated detailed investigations of the sources and intensities of sound in a gas flow. Basic research has been initiated on the noise arising from turbulent boundary layers.

Flight at high Mach Numbers involves a knowledge of high-intensity shock waves. Such waves can be conveniently studied in a shock tube in which waves are created by bursting a diaphragm separating two regions of gas at different pressures. Three shock tubes are in operation at the Institute of Aerophysics in which wave propagation and interaction and the resultant thermal states of the gases are being studied in detail.

The mathematical theory of fluid mechanics is under intensive review at present. While the semi-empirical theory that regards a gas as a continuous medium will prevail for some time to serve the needs of the design engineer, nevertheless, the molecular aspects of the mechanics of rarefied gases and of such effects as relaxation and dissociation associated with strong shock waves require a molecular approach to the theory of fluid motion. An important question for the future is whether it is possible to formulate a unifying molecular theory of fluid mechanics which will extend from free-molecule flow to the motion of very strong shock waves and include the well-known results of continuum theory. Some progress has already been made in this direction.

Air Safety Highlights

(*Continued from page 26*)

Lines, for his contributions in the field of fire prevention and cockpit standardization; and to Capt. H. G. Portman, Jr., of United Air Lines, for his initiative in improving pilot-management relations.

Colonel John Stapp, principal speaker at the dinner, gave an interesting off-the-record talk, augmented by slides and movies, on "Survival Problems in High-Altitude Ejection and the Operation of the High-G Car."

At least one precedent was set at this year's Seminar when the Foundation's untiring Director, Jerry Lederer, officially declared the afternoon of the 11th "free and open" for the delegates to visit some of the outlying pueblos. This little interlude, plus the hospitality of Dr. "Randy" Lovelace at his open house in Albuquerque on the final evening, gave an added touch to mark this Sixth Annual Air Safety Seminar as one of the most pleasant and fruitful ever held.

Effect of
Heavy Rainfall on Turbojet Aircraft Operation

JAMES W. USELLER,* WILLIAM LEWIS,* and EUGENE V. ZETTLE*

Lewis Flight Propulsion Laboratory, NACA

Introduction

With the increased frequency of commercial carrier flights employing turbojet engines and the extension of such air service into the more remote places of the earth, there exists increasing possibility that these aircraft will encounter heavy rainstorms during flight. Normally the flight would be diverted around the storm, but a particular condition such as landing might require operation through the rainstorm. Operation in heavy rainfall and the ingestion of large quantities of water into the turbojet engine even for a short period of time could influence the engine service life in addition to affecting the immediate performance output. Particular attention has been focused on the effect of the water ingested during operation in abnormally heavy precipitation.

Although no flight measurements were made, many experiments have been conducted at the NACA laboratory during which water was introduced into the inlet of turbojet engines and single combustors operating at simulated flight conditions. Applicable data from these investigations have been used to determine the quantities of water which can be taken into an engine without deleterious effect on the performance of each of the major engine components—namely, the compressor, the combustor, and the turbine. A secondary study of the effect of the ingested water on the engine bearings, accessories, and lubrication system has also been made.

Discussion

Estimates of Free Water in Air During Rainstorms

An estimate of the probable maximum moisture content for a range of altitudes has been made for the following assumed weather conditions:

(1) Tropical cumulus cloud; maximum cloud water, no precipitation.

(2) Moderate continuous rain; rainfall rate, 0.3 in. per hour.

(3) Heavy continuous rain; rainfall rate, 1.0 in. per hour.

(4) Heavy shower; rainfall rate, 2.0 in. per hour.

(5) Practical maximum rainfall; rainfall rate, 12.4 in. per hour.

Curves showing the estimated free water-air ratio as a function of altitude for each of these conditions are shown in Fig. 1.

The estimate for the tropical cumulus cloud is based on the cloud model used in reference 1. The curves for the other four cases are based on estimated conditions aloft required to produce the specified rainfall rate at the ground. The sea-level values in Fig. 1 were calculated directly from the assumed rainfall rate and the falling speed. At higher levels additional assumptions were necessary, and because of the uncertainty of the assumptions all values above 15,000 ft. are highly speculative.

The practical maximum rainfall rate of 12.4 in. per hour is the greatest water-air ratio considered herein and is a statistically estimated maximum rate such that, if a location is chosen at random in the United States east of the Rocky Mountains and the rainfall is observed for a period of 1 year, the probability is 1:1,000 that the rainfall rate will exceed 12.4 in. per hour for a period of 5 min. In terms of high-speed airplane operation, this probability level corresponds approximately to one encounter lasting one-half minute in 100 years of flight time and is intended to represent roughly the frequency of encounter which would constitute a significant operational problem. Considerably higher rainfall rates have been recorded,[2] but the rapid decrease of probability with increasing rainfall rate indicates that the probability of encountering values much in excess of those shown in Fig. 1 is extremely small.

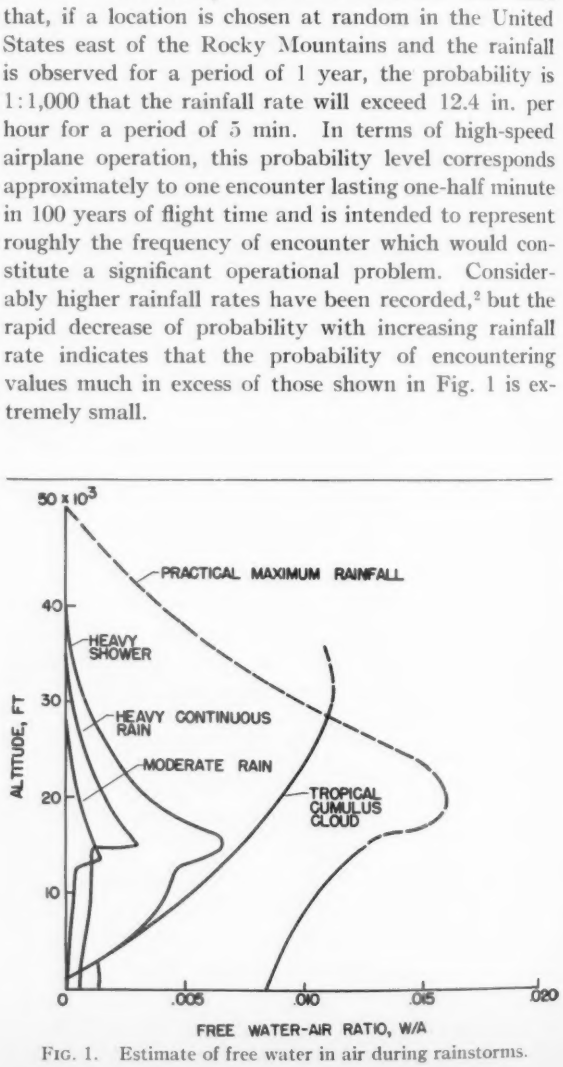


FIG. 1. Estimate of free water in air during rainstorms.

* Aeronautical Research Scientist.

The data for the maximum rainfall conditions considered in this paper are based on rainfall concentrations encountered in the Central and Eastern United States. A study of the existing recorded maximum rainfall concentrations throughout the world indicates that the practical maximum rainfall rate used herein may be applied without serious error to world-wide operation.

Free Moisture Inducted by Aircraft Air Intake

When an aircraft is flying, the air intake sweeps out a volume that is proportional to the frontal area of the inlet, and the quantity of water ingested is dependent on the flight Mach Number of the airplane and the inertia effects of the rain droplets. It can be assumed that the moisture content is homogeneously distributed throughout the volume swept by the inlet. Data for a typical subsonic inlet are shown in Fig. 2 and demonstrate that the engine would ingest about 100 per cent of the free water content at a flight Mach Number of 0.6. Considerably less water would be ingested at lower flight Mach Numbers, and as much as 144 per cent would be taken in at a flight Mach Number of 0.8. Therefore, the maximum free water-air ratios likely to be encountered at the engine inlet during subsonic flight are of the order of 1.44 times 0.016 or about 0.023 lb. of water per pound of air during flight at an altitude of 20,000 ft. The maximum water-air ratio to be ingested during high subsonic speed near sea level would be 0.012.

Effect of Free Water on Engine Component Performance

Numerous investigations were conducted which included the injection of water into the inlets of both centrifugal- and axial-flow turbojet engines operating both at sea level and at simulated flight conditions. Table 1 summarizes the pertinent results of these investigations that were conducted on production-model engines between 1948 and 1952 and shows the maximum water-air ratios injected and the limitations that prevented the injection of greater amounts of water into the engine.

In addition to the investigations of full-scale engine operation with the injection of water into the engine inlet, an investigation was conducted to isolate the influence of water ingestion on turbojet combustor operation. At each altitude investigated, water was sprayed into the inlet duct 62 in. upstream of the combustor until the combustor outlet temperature required for full-speed engine operation at a simulated flight Mach Number of zero without water injection at that altitude could be obtained regardless of fuel flow. The operating limits for 100 per cent rated rotational speed are based on actual test data at the correct combustor inlet conditions; the limits for 60 per cent speed were obtained by an extrapolation of these data. The same data were extended from a flight Mach Number of zero to a flight Mach Number of 0.6 by assuming constant compressor pressure ratio and constant corrected airflow through the engine.

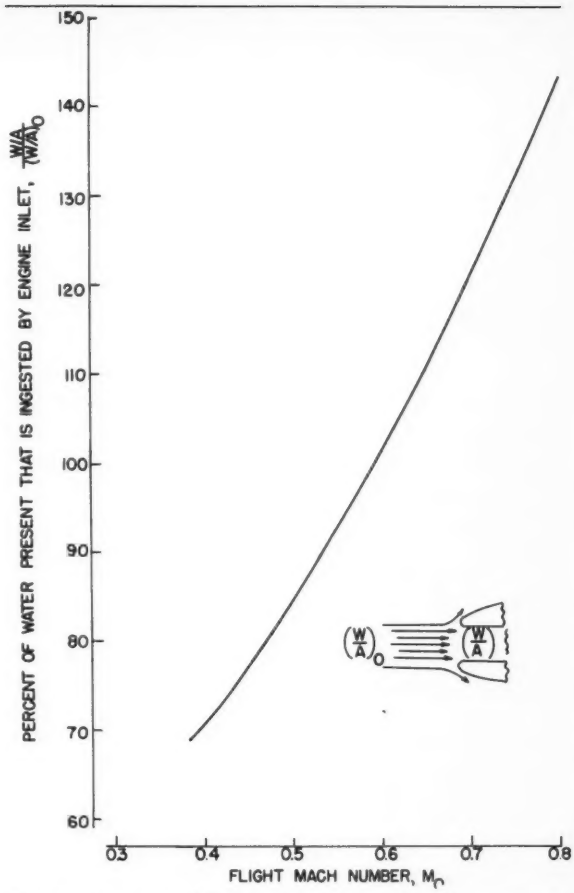


FIG. 2. Free water ingestion by engine inlet. Air scoop area, 2 sq. ft.: Based on constant engine airflow of 80 lbs. per sec.

Fig. 3 presents a comparison of the free water-air ratios ingested into a turbojet engine during flight through a maximum rainfall condition at a flight Mach Number of 0.6 and the combustor and compressor limitations determined during experimental investigations. The limitation for the compressor and accessories shown as a water-air ratio of 0.03 was taken from Table 1.

The combustion limitation curves shown in Fig. 3 are at values of free water-air ratios of approximately

TABLE 1

Engine	Maximum Water-Air Ratio	Limitation
C-1(centrifugal flow)	0.061	None encountered (centrifugal-flow compressor).
A-1 (axial flow)	0.030	Deterioration of compressor efficiency and necessary reduction of average turbine discharge gas temperature due to alteration of turbine temperature profile. Reported shortening of turbine life due to blade creep.
A-2 (axial flow)	0.032	Compressor blade rubbing and bearing failure due to contamination of bearing cooling air.
A-3 (axial flow)	0.030	Compressor blade rubbing was encountered during all operation above a water-air ratio of 0.01 but did not seriously hinder operation until 0.03 was attempted.

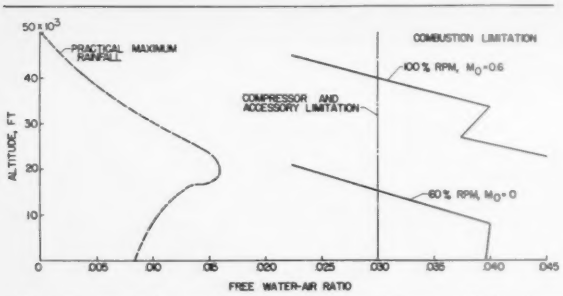


FIG. 3. Turbojet engine component performance limitations compared to free water-air ratios encountered during practical maximum rainfall condition.

twice those encountered during the most severe rainfall shown in Fig. 1. Reduction of the engine speed tended to lower the maximum operable altitude with any given water-air ratio, but the limiting water-air ratios still exceed those encountered during the maximum rainfall condition.

It can therefore be concluded that in spite of the somewhat approximate conditions involved, no combustion stability difficulties would be expected during a maximum rainfall condition even at the reduced speed conditions associated with landing approaches.

Effect of Free Water on Engine Accessories

The bearing failure reported in Table 1 for engine A-2 was due to contamination of the bearing labyrinth with water contained in the cooling air supply that transported the mist lubrication to the bearings. This source of trouble was eliminated in later models when a solid stream of oil was used to lubricate and cool the bearings. However, any engine that uses air bled from the compressor, either to cool the bearings or to balance the thrust of the components, would encounter contamination from the water that entered the compressor. The corrosive effects of water ingestion on gears, bearings, and accessories may also result in failures unless the water is removed. The water may be removed by operating the engine on dry air for a few minutes following wet operation.

CONCLUSIONS

The operating experience and data collected during simulated flight investigations that included the ingestion of water into a turbojet engine inlet and into a single combustor lead to the conclusion that no serious operational difficulties will be encountered because of copious ingestion of water during normal flight operation in zones of heavy precipitation. Water taken into bearing cooling and accessory systems will tend to corrode the metal parts unless precautions are taken to remove it within a short time.

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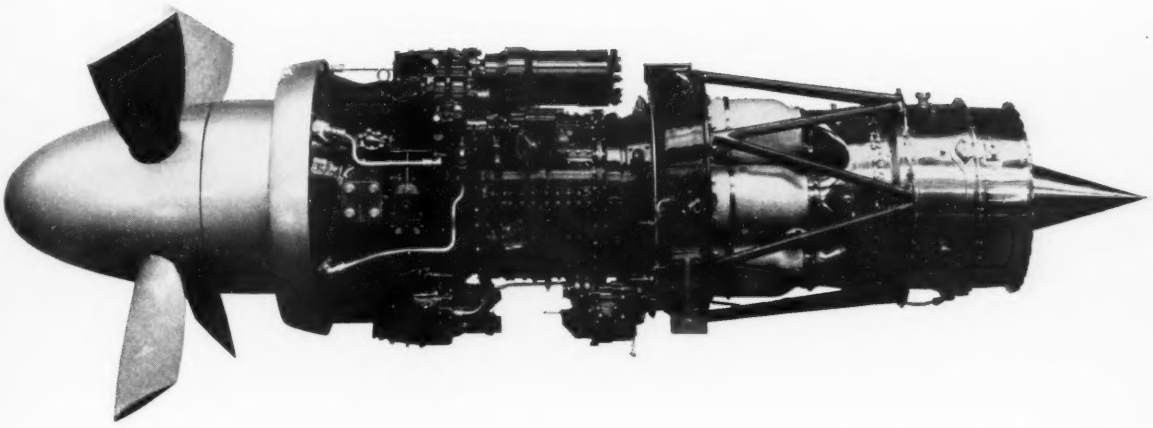
The Napier "Eland"



A. J. PENN*
D. Napier & Son Limited

Introduction

THE AERO GAS TURBINE DIVISION of D. Napier & Son Limited has for some years conducted intensive aerodynamic research on axial compressors, turbines, and air ducts connecting the main components of gas-turbine engines. Concurrently, research has been carried out on general mechanical problems such as blade vibration and reduction gear design, and this has resulted in a highly efficient turboprop engine of very low specific weight, known as the "Eland" engine. Furthermore, this research has enabled the "Eland" axial compressor to have the highest performance per stage of any known gas-turbine engine, a 7:1 compression ratio being achieved in ten stages. The reduction gear, which has been successfully subjected to considerable overload, has a low noise level and an extremely high mechanical efficiency.

The Aero Gas Turbine Division has long since realized the importance of research in support of the future aero-engine program and to this end has in recent years been building an extensive Research Station in the north of England which has recently been brought into full operation. This Research Station has a total installed power available for research on aero gas-turbine projects of approximately 40,000 hp.

As an indication of things to come, a compression ratio of 15:1 has been achieved on a single-shaft axial compressor at this Research Station.

Development of the engine is well advanced, and approval for flight has been achieved by a Special Category Test. Initial flight development is to be carried out in the Varsity aircraft, which is a twin-engined machine and will be powered by two Eland engines.

Future development of the Eland engine will be toward higher power, increased economy, and lower specific weight.

A derivative of the Eland engine is being employed for powering the Fairey Rotodyne aircraft. Also, the Eland is being considered for helicopter applications in addition to the Napier Oryx engine, which is under development now by the Aero Gas Turbine Division.

Description

The Napier Eland is a single-shaft propeller-turbine aero-engine that develops 3,000 e.hp. for a net dry weight of 1,575 lbs. Of conventional layout and mechanically simple in design, the Eland incorporates many features that have enabled the engine weight to be kept to a minimum and which have resulted in an extremely clean overall shape with a total frontal area of only 7.1 sq.ft. The economic fuel consumption together with the low specific weight make the engine suitable for both civil and military applications.

In the mechanical design of the engine, particular attention has been given to the requirements of servicing and overhaul. The engine is divided into four major assemblies comprising reduction gear, compressor, combustion system, and turbine. Each major assembly can be replaced individually so that, for example, when the turbine is removed, the reduction gear, compressor, and combustion system need not be disturbed. The combustion chambers and burners are separately removable, *in situ*, for inspection or replace-

* Chief Engineer, The Aero Gas Turbine Division.

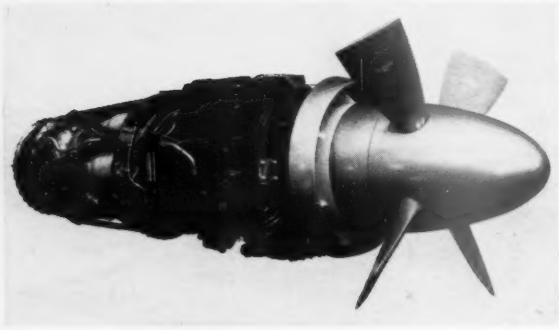


FIG. 2. Air intake assembly.

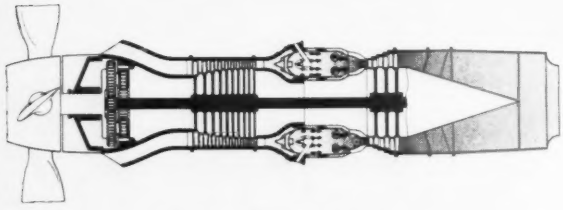


FIG. 3. Gas flow diagram.

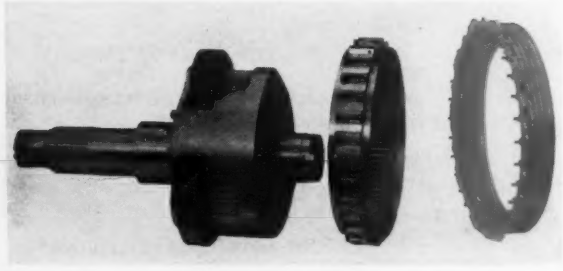


FIG. 4. Reduction gear and torquemeter assembly.

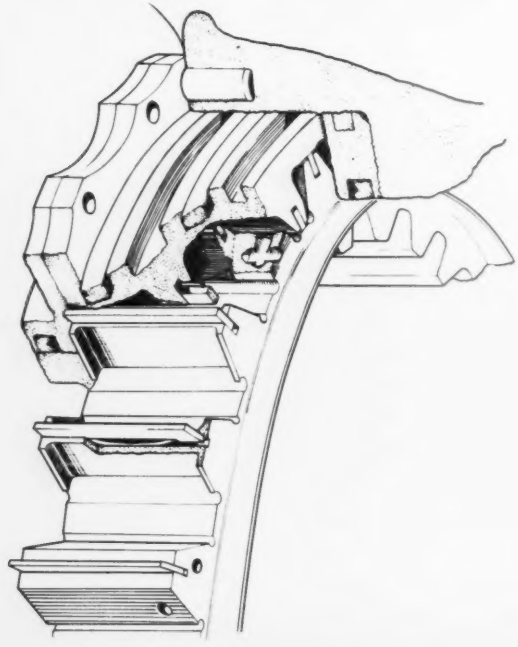


FIG. 5. Torquemeter, showing arrangement of sealing vanes.

ment, and free access is available to all engine accessories.

As a result of an intensive program of research on axial compressors carried out over a number of years, the characteristics of the compressor are such that the margin between surge and the economic operating line gives the engine excellent handling qualities.

Full advantage of the compressor characteristics has been taken in the design of the controls, and the engine has a rapid surge-free acceleration. The control system also embodies devices giving instantaneous protection in emergencies.

Although these outstanding features enable the Eland to offer great economies in conventional applications, the engine is capable of considerable development and is sufficiently versatile to be utilized for other special purposes such as the Fairey Rotodyne.

LEADING PARTICULARS

(1) *General*	
Maximum speed	12,500 r.p.m.
Direction of rotation (viewed from rear)	Left hand
Reduction gear ratios	0.0714:1, 0.0838:1, 0.0912:1, or 0.0972:1
(2) *Overall Dimensions*	
Maximum diameter	$36^{1}/_{16}$ in.
Length (front of propeller shaft to turbine exit flange)	$105^{1}/_{8}$ in.
Length (front of propeller shaft to end of turbine exit tail cone)	$122^{1}/_{4}$ in.
Overall frontal area (including accessories)	7.1 sq.ft.
(3) *Weights*	
Net dry weight less jet pipe (to EDM No. 25)	1,575 lbs. + $2^{1}/_{2}$%
Complete with starter and propeller governor	1,661 lbs.
Jet pipe (per foot run)	7.6 lbs.
(4) *Propeller*	
Type	Rotol hydraulic, four blades
Size	12 to 16 ft. diameter
(5) *Fuel*	
Wide-cut gasoline	D.E.R.D. 2486
Aviation turbine fuel	D.E.R.D. 2482
(6) *Lubricating Oil*	
Synthetic	D.E.R.D. 2487

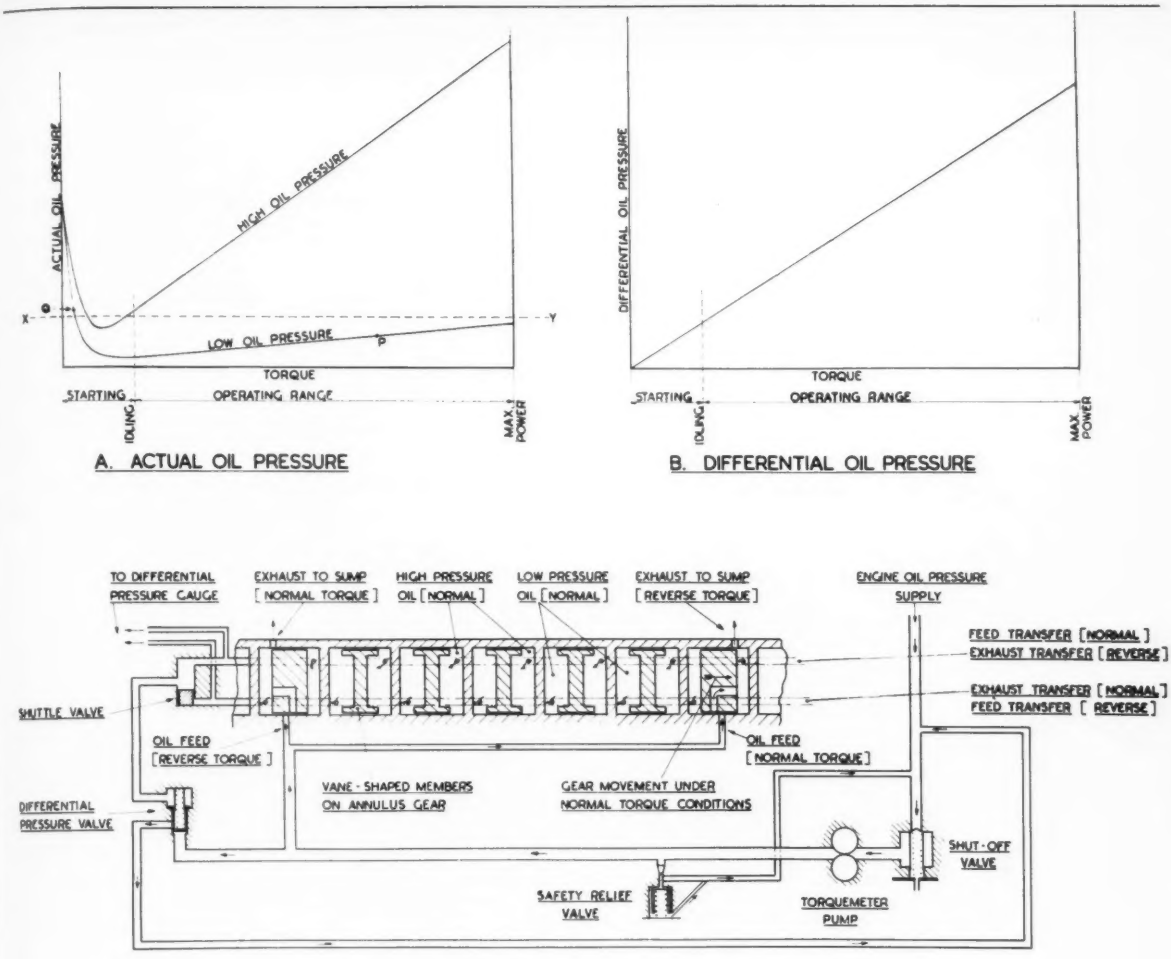


FIG. 6. Torquemeter vanes and porting arrangement.

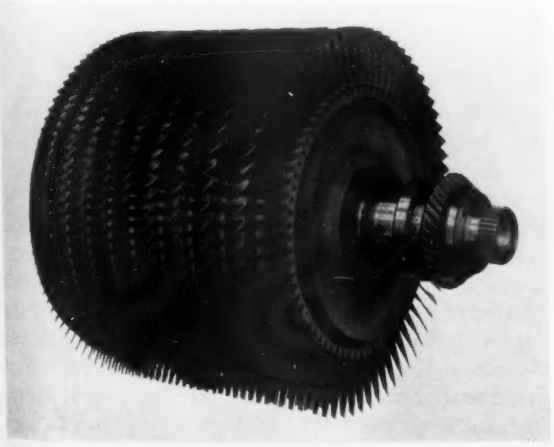


FIG. 7. Compressor rotor.

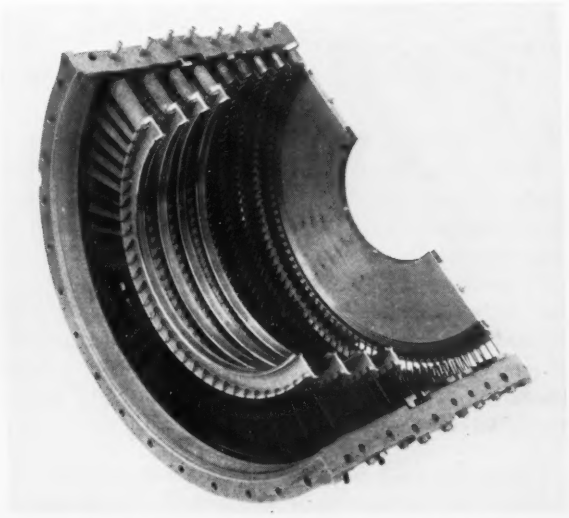


FIG. 8. Compressor half-casing and stators.

PERFORMANCE*

(1) *Sea Level, static* (I.C.A.N. Atmosphere)	
Take-off (12,500 r.p.m.)	2,690 s.hp. at 0.697 lb. per s.hp.-hr. 3,007 e.hp. at 0.624 lb. per e.hp.-hr.
Maximum continuous (12,000 r.p.m.)	2,070 s.hp. at 0.744 lb. per s.hp.-hr. 2,340 e.hp at 0.659 lb. per e.hp.-hr.
Cruising (11,500 r.p.m.)	1,665 s.hp. at 0.781 lb. per s.hp.-hr. 1,890 e.hp. at 0.688 lb. per e.hp.-hr.
(2) *Altitude* (30,000 ft., 400 m.p.h. T.A.S., I.C.A.N. Atmosphere)	
Operational necessity (12,500 r.p.m.)	1,575 s.hp. at 0.554 lb. per s.hp.-hr. 1,880 e.hp. at 0.463 lb. per e.hp.-hr.
Maximum continuous (12,000 r.p.m.)	1,325 s.hp. at 0.566 lb. per s.hp.-hr. 1,570 e.hp. at 0.478 lb. per e.hp.-hr.
Cruising (11,500 r.p.m.)	1,130 s.hp. at 0.573 lb. per s.hp.-hr. 1,310 e.hp. at 0.493 lb. per e.hp.-hr.
(3) *Oil Consumption* (cruising r.p.m.)	1 pint per hr.

TECHNICAL NOTES ON THE ELAND ENGINE

The Napier Eland (see Figs. 1† and 2) is a propeller-turbine aero-engine designed for use with a single-rotation, constant-speed propeller, the thrust of which is augmented by thrust from the jet. The engine consists of a ten-stage, axial-flow compressor delivering air to six combustion chambers in which fuel is atomized and burned continuously; the combustion products are delivered to a three-stage turbine and expelled to atmosphere through a propelling nozzle. The engine has a straight-through flow path (Fig. 3) with no sudden changes in direction, thus ensuring maximum aerodynamic efficiency. The compressor and turbine are mounted coaxially, and the propeller is driven through a reduction gear. Control of the engine is effected through an interconnected fuel metering unit and propeller governor, operated by a single lever. Automatic compensation is provided for changes in forward speed and ambient temperature and pressure conditions.

Reduction Gear

The reduction gear has a low noise level and a high mechanical efficiency. These important qualities result from the use of a compound-layshaft epicyclic gear train that incorporates a hydraulic torquemeter. Because of the construction of the torquemeter, the gearing is not mechanically fixed to the casing, and this, together with other self-centering devices, reduces vibration to a minimum and considerably improves transmission. Alternative reduction gear ratios are available to suit different installations.

A magnesium casting houses the reduction gear and incorporates the air intake.

From the compressor, drive is imparted through a quill shaft to a high-speed input pinion, supported at the rear end by a ball bearing and at the front by a roller bearing. The pinion drives three planet gears having integral layshafts, each mounted on two roller bearings and carrying a planet pinion meshed with the internal annulus gear.

The combined planet gear and layshaft assembly is carried on roller bearings in the two halves of a carrier that is integral with the propeller shaft. The carrier is supported at the front by a roller bearing and at the rear by a ball and roller bearing in the reduction gear casing. The ball bearing absorbs the propeller thrust.

Oil is delivered to the propeller hub through a feed in the propeller shaft and a transfer bearing mounted in the nosepiece of the casing on rubber rings. The rings act as an oil seal and, in addition, prevent any load from being taken by the transfer bearing instead of the roller bearing.

At the rear end of the propeller shaft, a bevel gear drives the oil pump assembly on the bottom cover; the accessories on the top cover are driven by a similar gear on the compressor shaft.

Torquemeter

The torquemeter (Fig. 5), which is built into the reduction gear annulus gear, consists of an annulus gear and a torque ring, each having several vane-shaped members carrying spring-loaded sealing vanes. The annulus gear is located inside the torque ring so that the vane-shaped members of each are interposed and spring-loaded against the annular walls between the opposite members by the sealing vanes. The spaces between the vane-shaped members form the high- and low-pressure chambers of the torquemeter and allow peripheral movement of the annulus gear. During normal operation, oil is supplied by a high-pressure pump through inlet ports (Fig. 6) to the high-pressure balancing cham-

* For further details see Performance Appendix, page 51.

† Fig. 1, the headpiece (page 43), shows the arrangement of accessories and support frame.

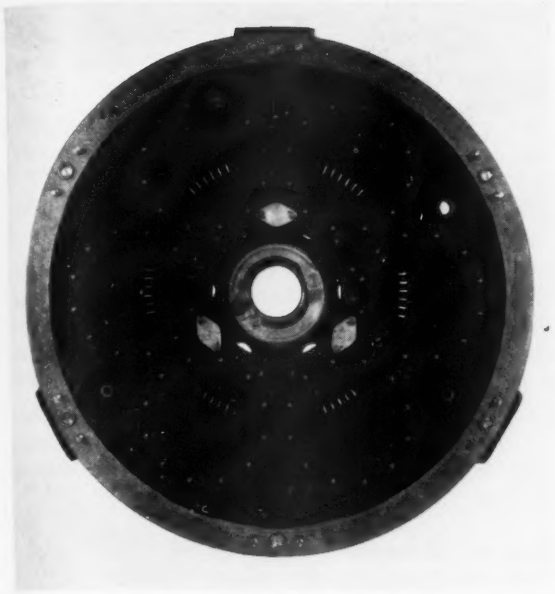


FIG. 9. Rear view of support plate.

FIG. 10. Combustion chamber.

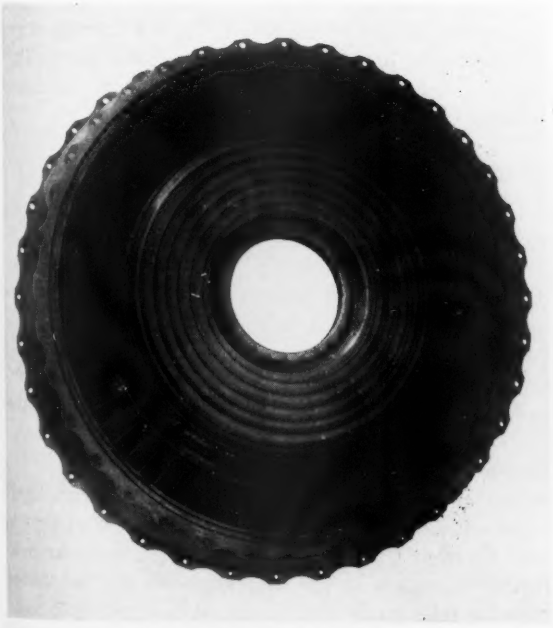


FIG. 13. Turbine nozzle assembly, stage 2.

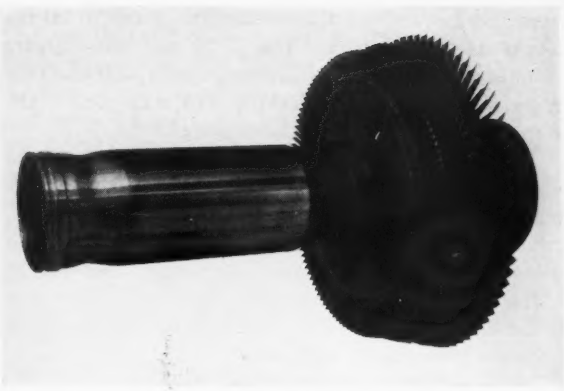


FIG. 11. Turbine rotor.

FIG. 12. Turbine nozzle assembly, stage 1.

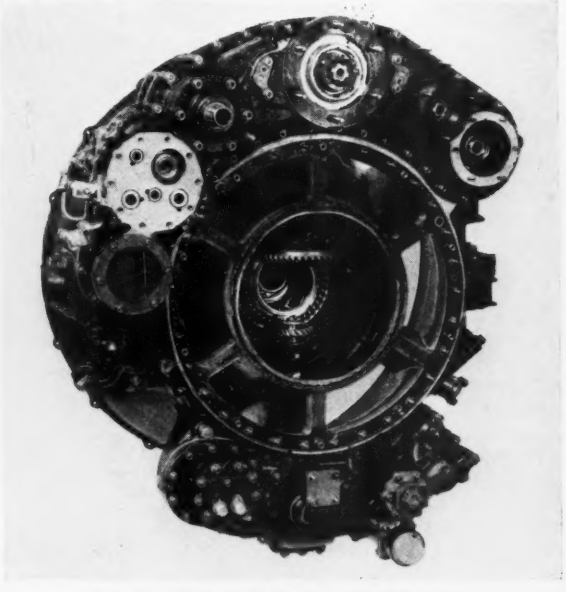


FIG. 14. Top and bottom accessory drives.

bers and leaks across the sides of the vanes to fill the low-pressure chambers. The high- and low-pressure chambers are separately interconnected by annular passages, and drain oil escapes through exhaust ports in the torque ring front cover to the engine sump.

As the torque increases on the annulus gear, the vanes move in relation to those on the torque ring, increasing the inlet port area and thereby increasing the oil pressure in the high-pressure chambers until the pressure is sufficient to balance the torque. Movement of the annulus gear also increases the exhaust port area to facilitate drainage of the now greater leakage of oil from the low-pressure chambers.

In the reversed torque condition, the ports in use for normal torque are closed by the relative movement of the annulus gear and torque ring, and other ports are uncovered to reverse the functions of the high- and low-pressure chambers. To obtain normal torque function, a shuttle valve is incorporated in the system so that high-pressure oil is still fed to the differential pressure valve.

By suitable connections to the pressure balancing chambers the torquemeter can be used to give signals for operating safeguard devices in the event of component failure.

From the curves in Fig. 6, it will be noted that, although the differential pressure signal from the torquemeter is linear with torque, the low-pressure signal has its peak at zero troque. This is a feature of the porting design. It will be realized, therefore, that if failure occurs, the torquemeter low-pressure signal will alter from a point such as P to a value Q. The safeguard unit consists of an arrangement that moves to the "guarding" position when the low pressure is above the level XY. The safeguard unit is rendered inoperative by a cock during starting and running up.

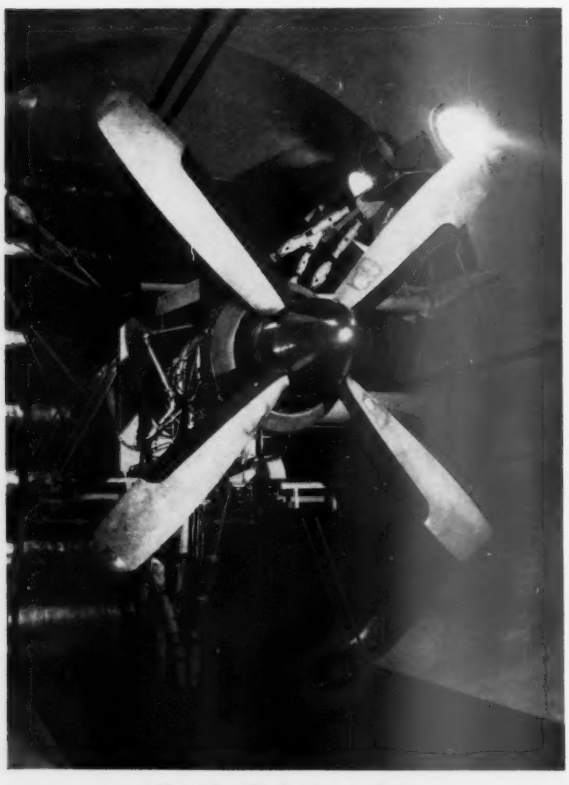


FIG. 15. Engine on test bed.

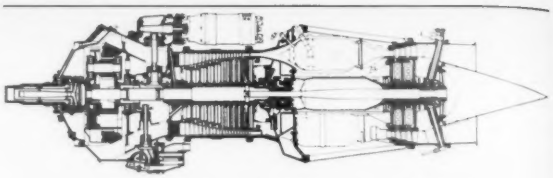


FIG. 16. Longitudinal section through engine.

Engine tests have consistently shown that the accuracy of the torquemeter over the normal power range is within ±1 per cent of the calibrated dynamometer readings.

Air Intake (*Anti-Iced*)

Air is delivered to the compressor through an annular, forward-facing intake that surrounds the reduction gear casing immediately behind the propeller and is designed to take full advantage of ram effect at forward speed.

The intake, in common with all other gas passages, has been flow tested and developed for maximum efficiency before incorporation in the final design.

Protection against icing of the intake and compressor inlet has been given careful study. The inner wall of the intake is heated by reduction gear oil splashed on the casings. Jackets have been designed for the outer wall of the intake through which reduction gear scavenge oil is circulated before being returned to the cooler. This scavenge oil is also circulated through the noses of the six spats in the intake which house the accessory drives and other essential services. The compressor inlet guide vanes are anti-iced by air tapped from a suitable stage in the compressor; the air heats both leading and trailing edges of the vanes before exhausting into the main stream at the inner diameter.

Compressor

Compressors to suit an engine of given mass flow can vary between low hub/tip ratio, high-speed, small-diameter and high hub/tip ratio, low-speed, large-diameter designs. In turboprop applications the former, although giving a lighter compressor, requires a larger reduction gear ratio and heavier gear box. The final design should, therefore, be a compromise to obtain the minimum engine weight. For this reason, the Eland compressor has been designed for a medium hub/tip ratio of 0.7.

The compressor characteristics obtained give optimum efficiencies on the engine operating line that is well removed from surge. The margin from surge is further increased at low engine speeds by the use of variable inlet guide vanes, and, as a result, extremely good engine handling and acceleration responses are ob-

tained without danger of surge. The inlet guide vanes are controlled by a speed-sensing servo unit.

A design pressure ratio of 7.0:1 has been achieved at 31 lbs. per sec. mass flow for the Take-Off Rating with only ten stages of blading.

The compressor is of simple construction comprising a disc and shaft-type rotor (Fig. 7) with two half-casings to which are bolted the stator rings (Fig. 8).

Aluminum-bronze blades are used throughout, and all the rotor blades are secured by fir tree roots to the compressor discs (see Fig. 7). These, in turn, are located over flank fitting splines to a hollow rotor shaft of S107 steel. For stages 1 to 7, the rotor discs are of aluminum and the remainder are of steel. The stators, which are of shrouded construction for the first four stages and cantilever for the remainder, are contained in the two halves of the L51 alloy compressor casing (see Fig. 8).

A ball and roller bearing at the front, and a roller bearing at the rear, support the compressor rotor shaft, which is connected to the turbine by a gear-type coupling.

To prevent windmilling while the aircraft is on the ground, a parking brake is fitted to the rear end of the compressor shaft (see Fig. 9).

Support Plate

Provision is made for mounting the engine from three pads on a support plate situated at the rear of the compressor. This casting in Z.T.1 light alloy (Fig. 9) includes the diffuser, between the compressor and combustion chambers, and an internally cast annulus into which air is bled from the diffuser for turbine cooling and cabin pressurization purposes.

Combustion Chambers

The combustion system, designed in conjunction with Messrs. Joseph Lucas Ltd., comprises six tubular-type chambers fitted with upstream injection burners. Each chamber and burner (Fig. 10) can be separately removed, *in situ*, without dismantling any other engine part. To facilitate withdrawal through the turbine frame each chamber is secured at either end by clamping rings.

Outer casings are fabricated in S.84 material and the flame tubes in D.T.D. 703. High-energy spark ignition plugs are provided in two of the combustion chambers from which the flame is propagated to the remainder by interconnectors. The use of upstream injection-type burners not only reduces the overall length of the system but gives good combustion at very high air/fuel ratios.

The engine operates satisfactorily on either kerosene or wide-cut types of fuels.

Turbine

For a turboprop engine it is necessary to extract as much power as possible from the turbine to give maximum shaft output. The available expansion ratio is fixed by the compressor pressure ratio and the back pressure imposed by the jet pipe and nozzle. To reduce the back pressure the final jet velocity is kept low relative to the turbine exit velocity. To achieve the maximum output from the turbine, without excessive weight penalty, a three-stage reaction-type turbine has been designed for the Eland at an expansion ratio of 5.5:1, with zero swirl to minimize jet pipe loss and turbine pressure.

The turbine comprises three separate bladed rotor discs mounted on a shaft and carried in a fabricated casing that contains the three nozzle assemblies.

Of H40 material, the rotor discs (Fig. 11) are mounted over flank fitting splines on the turbine shaft, which is supported at the rear by a ball bearing and at the front by the gear-type coupling driving the compressor. The combined rotor assembly (compressor and turbine) is mounted on three bearings and so arranged that the gyro-couples at the center bearing are in general canceled.

The rotor blades, which are of Nimonic 90 in stage 1 and Nimonic 80A in stages 2 and 3, are secured to the discs by fir tree roots.

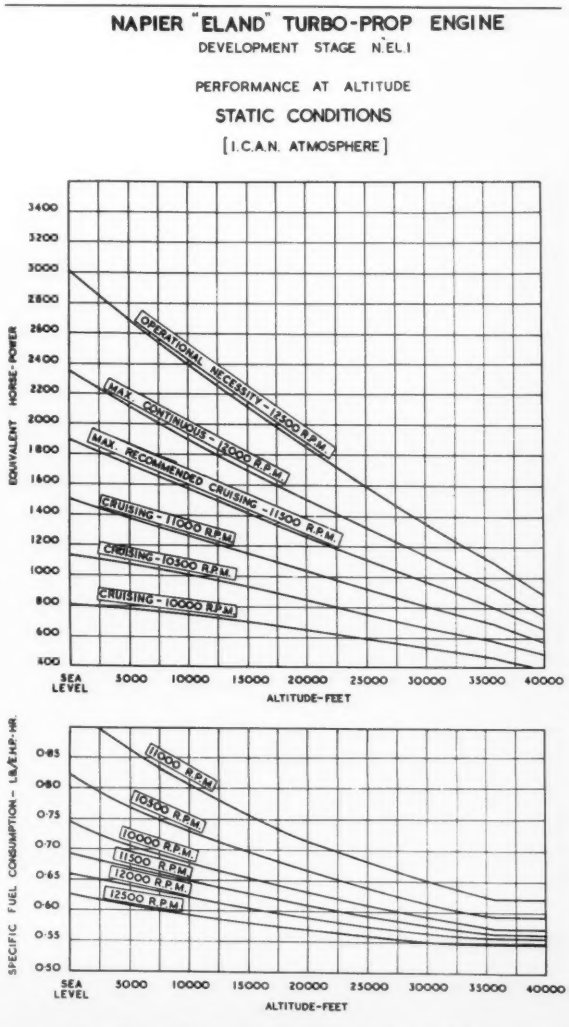


FIG. 17. Altitude performance, static conditions.

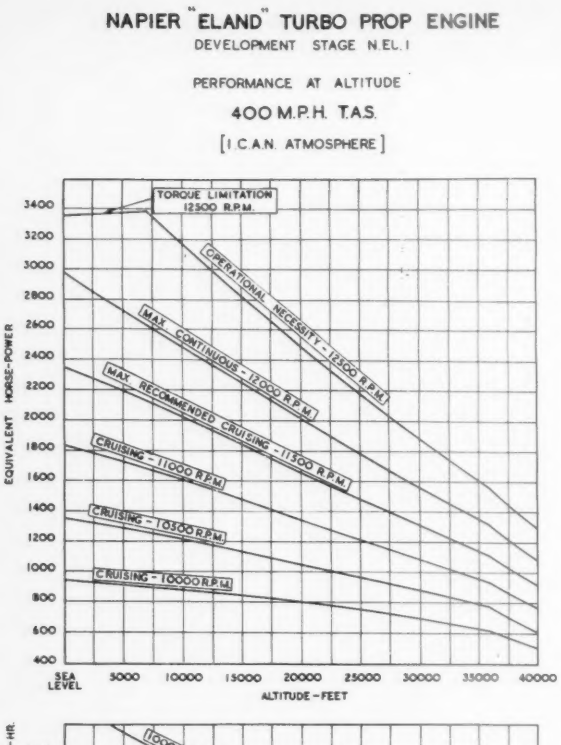


FIG. 18. Altitude performance, 400 m.p.h.

The blades are fitted in the disc so that a limited amount of tip rock is obtained. This allows for the differential expansion of the blades and discs, relieves root stresses, and ensures a large measure of vibration damping.

The nozzle blades are hollow and cast in X40 material, but the stage 1 blades (Fig. 12), which are secured by inner and outer rings, differ from those of stages 2 and 3, which have inner and outer platforms and are bolted to the external casing. The interstage seal plates (Figs. 13 and 16), which carry seals at the inner diameter and cooling scrolls on each face, are mounted from the nozzle rings by swinging links attached to several of the blade roots. This arrangement allows for differential expansion and ensures concentricity of the seals under operating conditions.

Engine Cooling, Pressure Balancing, and Sealing

Air is bled from the compressor to cool the turbine rotor discs, to supply air to the turbine and compressor balance pistons, to cool the compressor rear bearing and turbine bearing, and to supply air to the inlet guide vanes to give protection against icing (Fig. 16).

The front face of the stage 1 turbine rotor is cooled by compressor exit air, tapped from the diffuser. The air passes through the support plate annulus and is taken by three tubes to an annular chamber forward of the turbine. From here it flows between the front face of the disc and the front seal plate, through a scroll attached to the seal plate, and exhausts across the rotor blade roots to the trailing edge. The object of this scroll is to lengthen the path of the cooling air up the face of the disc.

Further air is tapped from stage 9 of the compressor and passes into the hollow shaft through a static shroud. This shroud contains vanes that remove the free vortex flow, which would otherwise exist in the air, and thereby increases the static pressure available. The rear face of the stage 1 disc, both faces of the stage 2 disc, and the front face of the stage 3 disc are cooled—by the air passing through scrolls on the interstage seal plates—from this supply. Air also passes out of the rear end of the shaft to pressurize the turbine balance piston chamber.

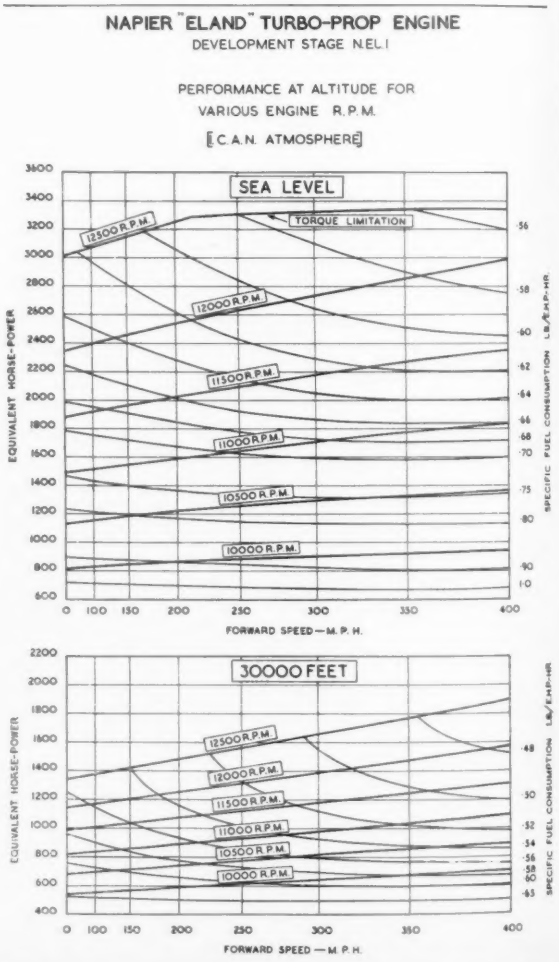


FIG. 19 Performance at various forward speeds, sea level and 30,000 ft.

PERFORMANCE APPENDIX

T.A.S., m.p.h.	Altitude, ft.	Engine, r.p.m.	s.hp.	Net Jet Thrust, lbs.	Fuel Cons., lbs. per hour	Spec. Fuel Cons., lbs. per e.hp.-hr.
Operational Necessity						
Static	Sea level	12,500	2,690	825	1,875	0.624
400	Sea level	12,500	2,900	560	1,861	0.555
Static	10,000	12,500	2,165	635	1,421	0.593
400	10,000	12,500	2,710	340	1,606	0.506
Static	20,000	12,500	1,665	475	1,049	0.567
400	20,000	12,500	2,105	290	1,203	0.483
Static	30,000	12,500	1,210	345	748	0.550
400	30,000	12,500	1,575	240	872	0.463
Maximum Continuous						
Static	Sea level	12,000	2,070	700	1,545	0.659
400	Sea level	12,000	2,640	255	1,697	0.569
Static	10,000	12,000	1,705	545	1,186	0.621
400	10,000	12,000	2,160	240	1,326	0.534
Static	20,000	12,000	1,360	415	892	0.587
400	20,000	12,000	1,720	220	1,015	0.503
Static	30,000	12,000	1,025	305	650	0.566
400	30,000	12,000	1,325	195	752	0.478
Maximum Recommended Cruising						
Static	Sea level	11,500	1,665	585	1,300	0.688
400	Sea level	11,500	2,160	150	1,430	0.607
Static	10,000	11,500	1,395	460	1,019	0.646
400	10,000	11,500	1,800	160	1,132	0.560
Static	20,000	11,500	1,115	355	774	0.613
400	20,000	11,500	1,445	155	864	0.526
Static	30,000	11,500	855	260	569	0.578
400	30,000	11,500	1,130	140	647	0.493

The turbine bearing and the rear face of the last-stage turbine disc are cooled in series with air taken externally through a pipe and filter from stage 4 of the compressor. Tappings from the filter supply the compressor rear bearing with cooling air and pressurize the seals on the airscrew and accessory bearings.

To heat the inlet guide vanes and to supply the compressor balance piston, air is taken forward through the hollow shaft from stage 5 of the compressor. No vortex breaker is fitted in this system, since the mass flow and pressure required are relatively low.

Jet Pipe

Both the inner cone and the jet pipe, which is fitted with a propelling nozzle, are of Nimonic 75.

Accessories

The engine accessories are mounted on the reduction gear casing disposed in two groups around the compressor (Fig. 14) and are readily accessible for servicing.

Of these, the fuel pump, tachometer, propeller governor, synchronizing alternator, and an aircraft accessory gear box drive shaft capable of transmitting 250 s.hp. are mounted on the top of the casing and are driven by a spiral bevel gear from the front end of the compressor shaft. The design of this bevel drive is unusual in that the thrust is taken by locating cones on each gear which help to ensure correct meshing, simplify fitting, and avoid the need for an additional thrust bearing.

At the bottom of the casing the pressure oil pump, torquemeter pump, and scavenge pumps are all driven from the propeller shaft by spiral bevel gears.

A Rotax electric starter is mounted above the front end of the compressor and motors the engine through the accessory gear box drive. Development is proceeding on alternative types of starting equipment.

Control

Control of the engine is effected by a single lever operating an interconnected propeller governor and Napier fuel metering unit that automatically compensates for changes in forward speed and ambient temperature and pressure conditions. An acceleration control is included in the unit to prevent overfueling and surging of the engine during acceleration. The fuel metering unit is reset by a two-position lever in the cockpit when compressor air is taken from the support plate for cabin pressurization.

A variable-datum turbine inlet temperature control, a maximum torque limitation device, automatic pitch coarsening, and an inlet guide vane control, which is responsive to engine speed, are also fitted.

Lubrication

The engine is supplied with oil from a pressure pump at 80 lbs. per sq.in. which, through a filter, delivers oil to the bearings, gears, torquemeter pump, and Purolator filter feeding the propeller governor. The pressure pump incorporates a relief valve that by-passes excess oil; and a static head valve, situated between the pump and filter, prevents flooding of the engine by oil from the tank under shutdown conditions.

Lubrication of the reduction gearing is effected by six sparge-type jets mounted on the planet carrier and by impinging jets that feed the planet shaft bearings; the high-speed pinion bearings and propeller shaft front bearings are splash lubricated. Calibrated jets supply oil to the compressor and turbine shaft bearings and to

(*Continued on page 60*)

Considerations in the Design of Structural Models

COLEMAN RAPHAEL*
Republic Aviation Corporation

Symbols

A = area, sq.in.
c = distance from bending axis to extreme fiber, in.
E = modulus of elasticity, lbs. per sq.in.
G = modulus of rigidity, lbs. per sq.in.
I = rectangular moment of inertia, in.^{4}
J = polar moment of inertia, in.^{4}
k = spring constant of supports
K = any constant
L = length, in.
M = bending moment, in.lbs.
N_L = prototype lengths/model lengths
N_F = prototype forces/model forces
P = load, lbs.
q = shear flow, lbs. per in.
s = stress, lbs. per sq.in.
T = torque, in.lbs.
Δ = linear deformation or deflection, in.
θ = angular deformation or deflection, rad.

Subscripts

P = prototype
M = model

Introduction

A structural model is one that, although not necessarily geometrically similar to its prototype, will faithfully reproduce, to some predetermined scale, the required structural characteristics. These may be stresses, strains, deflections, buckling loads, and/or some combination thereof. The primary purpose of building such a model is that it can generally be built with considerable simplification in shape. Hence it is possible to build a model that will give structural information before the prototype can be built, particularly if the prototype design involves lengthy machining operations. This paper discusses some of the considerations that must be taken into account in structural model design.

It will be assumed here that the complete prototype design is known, and the design of the model will be adapted to the information that is supposed to be determined from it. Principal points to be considered in such a design will therefore be discussed in turn.

Geometric Similarity

Ideal structural characteristics could be obtained from a model that is a geometric duplication of its prototype, in which all dimensions, fastenings, tolerances, etc., have been reduced (or enlarged) to the same scale. While this will evidently yield the most exact results, the difficulties inherent in the fabrication of such a model generally negate its value. Since no machined contours are eliminated, and the sizes of fasteners, holes, and tolerances become nonstandard, it is almost always easier and quicker to build the prototype than its model. In addition, if the model is to a considerably smaller scale, it becomes increasingly difficult to maintain geometric similarity in the fabrication and assembly of detail parts.

It is therefore good general practice to design the model for its structural characteristics alone, using the prototype detail dimensions only to serve as a guide to the general shape that will best match the desired parameter.

Scale Factor

The choice of scale factor determines the overall size of the model. This scale factor will not apply to all dimensions (since the model is not a geometric representation) but only to those that are involved in the duplication of results. This will be discussed later in this report. In an airplane wing or stabilizer, for example, the scale factor would be applied to the span (and generally the chord) dimensions but not necessarily to the heights.

It is commonly thought that a large reduction in model size always represents economical design. This is in most cases untrue. The major cost is involved in the design and manufacture of the model, rather than in the material of which it is made. The time required for design of the model varies very little with the magnitude of the scale factor, and it is generally easier to assemble large formed parts than small ones, where edge distances and tiny fastener sizes represent a problem. Sometimes, because of insufficient space, adhesive bonding must be used to fasten joints.

It is therefore a good idea to make structural models of major air-frame components full size, if possible. This, of course, refers to such structures as wings, stabilizers, and fighter aircraft fuselages. It would not be practical to build full-scale models of larger structures, such as transports or dirigibles.

Boundary Conditions

The boundary conditions of a structural model should be duplicated as carefully as possible. The supporting structure of the prototype may have edges that are free, fixed, hinged, or partially fixed, and the model supports should be the same. The duplication of fixed or hinged edges is a simple design problem; in the case of partial fixity, however, this duplication becomes more complex. It can be accomplished by determining the spring constant, k_P, of the prototype support, and designing the model support to have a

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spring constant $k_M = (N_L/N_F)k_P$. The reason for this ratio will be evident from the discussion to follow.

Design Equations

Let the selected scale factor be $N_L = L_P/L_M$. Assume that an arbitrary ratio is selected which will relate forces on the prototype to those on the model. Then $N_F = P_P/P_M$. Let us now impose the condition that linear deflections on the model must represent those of the prototype reduced by the model scale factor. Therefore, in order for axial deflections to be proportional to N_L,

$$N_L \frac{P_M L_M}{A_M E_M} = \frac{P_P L_P}{A_P E_P}$$

$$\therefore A_M = N_L \frac{P_M}{P_P} \frac{L_M}{L_P} \frac{E_P}{E_M} A_P = \frac{1}{N_F} \frac{E_P}{E_M} A_P \qquad (1)$$

If bending deflections are to be correlated,

$$N_L \frac{P_M L_M^3}{E_M I_M} = \frac{P_P L_P^3}{E_P I_P}$$

$$\therefore I_M = N_L \frac{P_M}{P_P} \frac{L_M^3}{L_P^3} \frac{E_P}{E_M} I_P = \frac{1}{N_F N_L^2} \frac{E_P}{E_M} I_P \qquad (2)$$

If any angular rotations occur, the distance from any point to the center of twist is smaller on the model than on the prototype. Hence, for linear deflections to be smaller by the same ratio, angular deflections on both model and prototype will have to be equal:

$$\frac{T_M L_M}{G_M J_M} = \frac{T_P L_P}{G_P J_P}$$

$$J_M = \frac{T_M}{T_P} \frac{L_M}{L_P} \frac{G_P}{G_M} J_P = \frac{T_M}{T_P} \frac{1}{N_L} \frac{G_P}{G_M} J_P$$

If the scale factor N_L has been applied to transverse as well as longitudinal directions, T_M and T_P may be replaced by $P_M L_M$ and $P_P L_P$ respectively: then,

$$J_M = \frac{P_M L_M}{P_P L_P} \frac{1}{N_L} \frac{G_P}{G_M} J_P = \frac{1}{N_F N_L^2} \frac{G_P}{G_M} J_P \qquad (3)$$

In Eqs. (1), (2), and (3), N_L and N_F are independent and arbitrary ratios of length and load. Their selection would depend upon desired model size, available loading equipment, and other incidental factors. The closest approximation to geometric similarity, however, can be obtained by making $N_F = N_L^2$. If this is done, Eqs. (1), (2), and (3) become

$$A_M = (E_P/E_M)(A_P/N_L^2) \qquad (4)$$

$$I_M = (E_P/E_M)(I_P/N_L^4) \qquad (5)$$

$$J_M = (G_P/G_M)(J_P/N_L^4) \qquad (6)$$

In this case all areas, which have the units of a linear dimension to the second power, are reduced by the square of the linear reduction ratio, and all inertias, which are expressed as a linear dimension to the fourth power, are reduced by the fourth power of the linear reduction ratio. This is the condition that would prevail if the model were a geometric duplication of the prototype. If, finally, the model and prototype are both to be made of the same material, $E_P = E_M$, $G_P = G_M$, and the equations become

$$A_M = A_P/N_L^2 \qquad (7)$$

$$I_M = I_P/N_L^4 \qquad (8)$$

$$J_M = J_P/N_L^4 \qquad (9)$$

Summary of Design Equations

For structural similarity, with a scale factor N_L applying to longitudinal and transverse lengths:

Type I:

$$A_M = \frac{E_P A_P}{E_M N_F}; \qquad I_M = \frac{E_P I_P}{E_M N_F N_L^2}; \qquad J_M = \frac{G_P J_P}{G_M N_F N_L^2} \qquad (1, 2, 3)$$

For close approximation to geometric similarity:

Type II:

$$A_M = \frac{E_P A_P}{E_M N_L^2}; \qquad I_M = \frac{E_P I_P}{E_M N_L^4}; \qquad J_M = \frac{G_P J_P}{G_M N_L^4} \qquad (4, 5, 6)$$

and, if prototype and model material are the same:

Type III:

$$A_M = \frac{A_P}{N_L^2}; \qquad I_M = \frac{I_P}{N_L^4}; \qquad J_M = \frac{J_P}{N_L^4} \qquad (7, 8, 9)$$

Model and Prototype Relationships

The following relationships follow immediately from the foregoing design equations:

Bending Deflections

$$\frac{\Delta_M}{\Delta_P} = \frac{\dfrac{KP_M L_M^3}{E_M I_M}}{\dfrac{KP_P L_P^3}{E_P I_P}} = \frac{P_M}{P_P} \left(\frac{L_M}{L_P}\right)^3 \left(\frac{E_P}{E_M}\right) \frac{I_P}{I_M}$$

$$= \frac{1}{N_F} \frac{1}{N_L^3} \frac{E_P}{E_M} \left(\frac{E_M}{E_P} N_F N_L^2\right) = \frac{1}{N_L} \qquad (10)$$

Torsional Angular Deflections

$$\frac{\theta_M}{\theta_P} = \frac{K\dfrac{(P_M L_M) L_M}{G_M J_M}}{K\dfrac{(P_P L_P) L_P}{G_P J_P}} = \frac{P_M}{P_P} \left(\frac{L_M}{L_P}\right)^2 \frac{G_P}{G_M} \frac{J_P}{J_M}$$

$$= \frac{1}{N_F} \frac{1}{N_L^2} \frac{G_P}{G_M} \left(\frac{G_M}{G_P} N_F N_L^2\right) = 1 \qquad (11)$$

Eqs. (10) and (11) apply to structural models of all three types.

TABLE 1
Summary of Model and Prototype Relationships

		Type I	Type II	Type III	Type IV (Geometrically Similar, Same Material)
Bending deflections	$\frac{\Delta_P}{\Delta_M}$	N_L	N_L	N_L	N_L
Torsional angular deflections	$\frac{\theta_P}{\theta_M}$	1	1	1	1
Bending and twisting moments	$\frac{M_P}{M_M}$	$N_F\ N_L$	$N_L{}^3$	$N_L{}^3$	$N_L{}^3$
Axial stresses	$\frac{s_P}{s_M}$	$\frac{N_F}{N_L{}^2}$	1	1	1
Bending stresses	$\frac{s_P}{s_M}$	$\frac{E_P}{E_M}\ \frac{c_P}{c_M}\ \frac{1}{N_L}$	$\frac{E_P}{E_M}\ \frac{c_P}{c_M}\ \frac{1}{N_L}$	$\frac{c_P}{c_M}\ \frac{1}{N_L}$	1
Torsional shear flow	$\frac{q_P}{q_M}$	$\frac{A_M}{A_P}\ N_F\ N_L$	$\frac{A_M}{A_P}\ N_L{}^3$	$\frac{A_M}{A_P}\ N_L{}^3$	N_L

Bending and Twisting Moments

Type I:

$$M_M/M_P = P_M L_M / P_P L_P = 1/N_F N_L \tag{12}$$

Types II and III:

$$M_M/M_P = 1/N_F N_L = 1/N_L{}^3 \tag{12a}$$

Axial Stresses

Type I:

$$\frac{s_M}{s_P} = \frac{\frac{P_M}{A_M}}{\frac{P_P}{A_P}} = \frac{P_M A_P}{P_P A_M} = \frac{1}{N_F} N_L{}^2 = \frac{N_L{}^2}{N_F} \tag{13}$$

Types II and III:

$$s_M/s_P = 1 \tag{13a}$$

Bending Stresses

$$\frac{s_M}{s_P} = \frac{\frac{M_M c_M}{I_M}}{\frac{M_P c_P}{I_P}} = \frac{M_M}{M_P}\ \frac{c_M}{c_P}\ \frac{I_P}{I_M}$$

Types I and II:

$$\frac{s_M}{s_P} = \frac{1}{N_F N_L}\ \frac{c_M}{c_P}\left(\frac{E_M}{E_P}\ N_F N_L{}^2\right) = N_L \frac{c_M}{c_P}\ \frac{E_M}{E_P} \tag{14}$$

Type III:

$$s_M/s_P = N_L(c_M/c_P) \tag{14a}$$

If the model has been designed so that heights as well as lengths are reproduced to the scale factor N_L, then $N_L(c_M/c_P)$ will be equal to 1 and the stresses in the Type III model will be duplicated.

Torsional Shear Flow (Thin-Walled Cellular Structures)

Type I:

$$\frac{q_M}{q_P} = \frac{\frac{T_M}{2A_M}}{\frac{T_P}{2A_P}} = \frac{T_M}{T_P}\ \frac{A_P}{A_M} = \frac{1}{N_F N_L}\ \frac{A_P}{A_M} \tag{15}$$

Types II and III:

$$q_M/q_P = (1/N_L{}^3)(A_P/A_M) \tag{15a}$$

If the model has been designed so that cellular enclosed areas have been reproduced to the scale factor $N_L{}^2$ (a natural consequence of duplicating heights, as well as lengths), then for all three types of models

$$q_M/q_P = 1/N_L \tag{15b}$$

In a similar fashion, it is evident that the relationship between any physical quantities can be determined in terms of the basic dimensional parameters.

Table 1 gives a summary of model and prototype relations. These relationships are valid when the applied model load is $1/N_F$ times the prototype load.

DIMENSIONAL RELATIONSHIPS

A significant fact that applies to all the relationships in the Type IV model, and most of those in the Types I, II, and III models, can now be stated: in general, the relationship between similar quantities in the prototype and model can be determined directly from the dimensional units of the quantity being duplicated. Thus, if axial stress is expressed in terms of units of force per square unit of length, the numerator will be decreased by N_F and the denominator by $N_L{}^2$, from which $s_P/s_M = N_F/N_L{}^2$. If $N_F = N_L{}^2$, then $s_P/s_M = 1$. Angular deflections, which have no units, will be duplicated, and all linear deflections will be decreased by N_L. In the Type IV model, we can imagine ourselves transformed to a regime where the three basic physical units—time, distance, and force—are multiplied by 1, $1/N_L$ and $1/N_F = 1/N_L{}^2$, respectively. All physical quantities, which must be expressed in terms of these units, can now be determined. For example, consider the prototype to have a support of spring constant k lbs. per in. The numerator of the model will, therefore, be decreased by $N_F = N_L{}^2$, and the denominator by N_L. It, therefore, follows that $k_P/k_M = N_L{}^2/N_L = N_L$. Similarly, if the units of our spring are in radians per inch pound, k_P/k_M will be equal to $1/N_F N_L = 1/N_L{}^3$

Joint Rigidities

The most difficult portions of a prototype structure to duplicate are its internal joints. Here, if the model is not to prototype scale, it is generally not feasible to make a geometrically similar joint, inasmuch as this involves nonstandard sizes of fasteners, holes, and tolerances. Instead, the joints should be designed to accommodate the load that is transmitted through them. In general, this will ensure sufficient joint rigidity such that they will contribute a negligible part to the total deflection of the structure. However, cases sometimes exist in which the "tightness" of particular major joints is of primary importance in determining the structural deflection characteristics. Such joints, which can only be selected through the discerning eyes of the experienced engineer, can be made satisfactorily rigid through the use of close tolerances and interference fit assemblies.

Test Setup

Despite the accuracy with which the structural model is designed, the test results will be of little value unless many precautions are taken in the design of the jig, loading setup, and testing procedure. Support deflections, for example, are a common source of error, extremely difficult to eliminate. If the model is to be cantilevered from a rigid support, for instance, some error in deflections must be tolerated, inasmuch as it is impossible to make a support infinitely rigid. There are four ways of compensating for such errors in model deflection:

(1) Make the model, supports, and load symmetric about and continuous across the plane representing the desired fixed end. In this case the slope at this "fixed end" will remain horizontal and not contribute to the model deflections.

(2) Using the desired "fixed end" location as a datum, extend a framework supported from this datum plane, and measure all model deflections with dial gages mounted to this framework. In this way all deflections will be read relative to the "fixed ends," which is the desired objective.

(3) Design the specimen so that it overlaps the fixed end, and attach a hydraulic cylinder to the overlapped part, as shown in Fig. 1. Mount an inclinometer to the section that is supposed to be "fixed." As load is applied, this section will rotate. The hydraulic cylinder must then be actuated to restore the inclinometer reading to zero. Deflection measurements may then be made.

(4) Make the support as rigid as possible, and then measure its deflection carefully. From the support

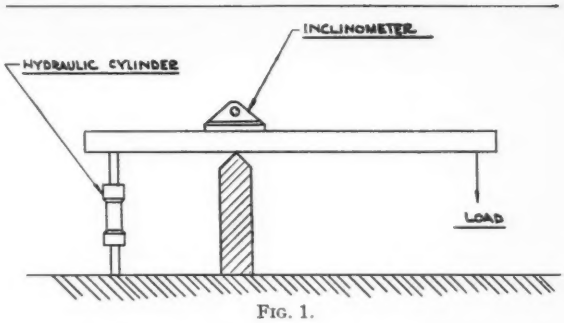

Fig. 1.

rotation, rigid body deflection corrections can be applied to all the measured deflections.

In using the last method, one must be extremely careful in measuring the rigid body rotation, as a very slight error may affect the results a considerable amount, particularly for relatively rigid structures with deflection points some distance away from the fixed end.

Several methods may be used for the application of load. These include loading through tension pads, turnbuckles, or hydraulic cylinders. Up loads may be applied through jacks that are supported on weighing scales. All of these load application methods are common enough to require no explanation here.

The recommended method of measuring deflections is by dial gages mounted on the floor or from an overhead bridge structure. If the deflections are extremely large, steel scales may be hung from the model and observed through a transit or measured with fixed pointers attached to the ground. Electric strain gages are commonly employed for the determination of stresses throughout the structure.

Inasmuch as no built-up structure evidences perfect elastic behavior at the beginning of load application, some initial load should be applied before deflection readings are taken. Several readings for incremental load applications should then be taken. In the subsequent analysis, plots should be made of deflection vs. load, and the slope of the plotted straight line submitted in the final results.

As a final precaution, the model designer should be reminded of the inexactness of experimental measurements. Every attempt should be made to avoid errors and take check readings wherever possible. If, for example, strain gages are used to determine load distribution throughout the structure, all reactions should also be measured so that a check is available for analyzing the load distribution around end joints. If the engineer is forever aware of the precautions he must constantly observe, the results obtained from the test of a structural model can be of invaluable aid in the design and analysis of the prototype structure.

Air Traffic Control and the Turbojet Aircraft

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DISCUSSION OF THIS SUBJECT, particularly as it relates to civil transport-type aircraft, is quite premature since there is a lack of knowledge and experience in this phase. In preparing my discussion, I have had the advantage of reference to studies of "Simulated Jet Transport Operations," by R. D. Kelly and H. B. Kaster of United Air Lines, Inc., and to several papers by Douglas Fraser, formerly of the British Embassy staff in Washington. In addition, for a number of months our office has been engaged in an intensive study of current turbojet aircraft operations and the problems arising therefrom. Although our studies are still in the phase of defining the problem areas, the general picture is beginning to shape up, and some preliminary conclusions can be drawn at this time.

Military turbojet aircraft accounted for about 25 per cent of military flying hours last year and are anticipated to increase to over 30 per cent this year. Because of the general impracticability of expecting Visual Flight Rule weather conditions extending from the surface to the high altitudes used by jet aircraft, the great majority of these operations must be conducted on Instrument Flight Rule flight plans. It is felt, therefore, that almost half of the military IFR traffic (which constituted approximately 40 per cent of our total IFR traffic) was due to flights of turbojet military aircraft.

Our current studies are aimed at defining the specific problem areas, developing an immediate corrective program, and examining the airways system, including communication, navigation, and air traffic control facilities and procedures, to determine a basis for future planning. We have become immediately aware that the "jet problem" is not a problem as such but rather a collection of troubles common to conventional aircraft operations which are intensified by the greater speeds, higher altitudes, and faster fuel consumption rates of jet aircraft.

It is inappropriate to use the survey of our present operating problems with jet aircraft as a preview of the operation of civil turbojet transports. Much of our current difficulty is due to operating requirements of a military nature and a lack of modern air-borne navigation equipment in military aircraft. This picture is further distorted by the ability of the military services to assign "priorities" among military aircraft at military air bases, permitting the handling of jets as first priority operations.

These studies, however, do give some preliminary indications of potential problem areas in the extensive future use of the turbojet transport—and indicate a requirement for "arbitration" between the operating requirements designed into those aircraft and the system requirements for air traffic control. The fundamental precepts of the air traffic control system, as developed over the past 20 years, will require adjustment to accommodate a mixed traffic flow of conventional and turbojet aircraft. It appears probable, too, that the operating requirements of turbojet aircraft for maximum economy, range, and utility—based upon the ideal situation—will need to be compromised to some extent—under Instrument Flight Rule conditions—to facilitate the absorption of any large number of such aircraft into the present air traffic flow without undue penalty upon the operators of conventional aircraft.

One fundamental of the existing air traffic control system is the precept of "first come, first served" wherein the only deviation is the handling of aircraft in an emergency. There is no provision in the system for the juggling of an approach sequence, for example, to permit a higher aircraft to land ahead of aircraft that have arrived earlier and are holding at lower levels awaiting their turns to commence an approach. The IFR flow pattern of conventional aircraft provides for the usage, normally, of the higher levels for through traffic. Aircraft approaching a destination are dropped to successively lower levels and fed into the top of one or more holding patterns. These holding patterns act as "pressure tanks" into which aircraft flow at the top, in surges, at random intervals, and out the bottom of which comes a steady stream of landing aircraft at regularly spaced intervals. Using one holding pattern, a landing rate of one aircraft every 3 min. is normal. This can be increased to a possible landing rate of one every 90 sec., using two or more holding patterns and feeding aircraft alternately into the final approach to the landing runway. In this high-volume system, the common final approach path—that is, the straight flight path along the extended center line of the landing runway—is kept as short as possible since spacing between successive aircraft is accomplished by turns and other maneuvers. The effect of widely divergent speeds of successive aircraft on spacing along the final approach path decreases to a negligible amount if this portion of the flight can be kept to minimum length.

Conversely, in the current operation of turbojet aircraft, economy and efficient operation require cruising at extremely high altitudes, well above all conventional traffic, and the maintenance of such high altitudes until ready to start an approach for a landing. The operating characteristics of such aircraft militate against the acceptance of any traffic clearances but an uninterrupted

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descent to touchdown, without leveling off at an intermediate altitude or delay of any kind. Any holding over the destination must be of extremely short duration and at cruising altitude. This delay at altitude is preferred to the acceptance of a clearance to descend which includes any limitation, restriction, or qualification other than "cleared to land."

Because of the use of altitudes in the range of 10,000 to 25,000 ft. for en-route or through conventional traffic and the need by jet aircraft for relatively uninterrupted climb after departure to cruising altitudes in excess of 25,000, it is seldom possible to authorize such climbs "on course." More frequently, it is necessary to require climbs at an angle of 45° or more to the intended line of flight until the jet is above other traffic before resuming the intended course.

In cruising at the higher levels there has been, as yet, little difficulty, primarily because of the relatively low traffic volume and extensive use of "at least 500 on top of all clouds" as an altitude assignment, reducing the problems of discrete altitude assignment. Two factors will provide potential, new operating problems, however, as the turbojet traffic volume increases: (a) altimeter inaccuracies, and (b) "cruise control" practices designed for maximum jet efficiency wherein a constantly changing cruising altitude is desired. It has been found that the standard aircraft altimeter instrument errors are multiplied at the higher altitudes through instrument error, temperature effect, and instrument lag (in high-rate climb or descent) to an extent requiring greater vertical spacing between aircraft. Pending further study, we have established as an interim measure that aircraft above 30,000 ft. shall be separated vertically by at least 2,000 ft.—twice that required at lower levels. This has the effect of reducing the available cruising levels above that altitude to one-half. An additional complicating factor concerns the desirability of eliminating all VFR-type operation at the higher levels, requiring all to operate at discrete assigned altitudes. This would eliminate use of "500 on top" cruising altitudes.

In some of the larger military turbojet aircraft we find that the most economical cruise power requires that a lower cruising altitude be used when the aircraft is most heavily loaded, with the altitude being increased constantly as the fuel load is decreased. The advantages of such fuel economies must be weighed carefully against the resultant extravagant use of airspace by such a method of operation.

The big problem arises when the turbojet aircraft nears its destination. Today, at the larger terminals where our air traffic control and navigation system is completely implemented, there are the aforementioned steady streams of landing traffic from the holding patterns. These streams may consist of as many as eight to twelve aircraft in various stages of leaving the holding patterns—being vectored toward the final approach, on final approach, and occupying the runway during landing roll—all spaced at a minimum interval of 3 miles. The jet aircraft arriving at such a terminal and insisting upon maintaining cruising altitude until air traffic control was prepared to guarantee a relatively uninterrupted descent—any holding thereafter to be limited to a maximum of 10 min. and above 20,000, with "clearance to land" issued before the aircraft descended below that level—would pose a considerable problem. It would require the halting of all other traffic at outer holding points as the jet leaves its cruising altitude; completion of all approaches in progress before the jet was cleared below 20,000; and then a hiatus in normal traffic flow until the jet was at a point where landing was assured, with no possibility of a missed approach. This type of requirement has actually been voiced as necessary to turbojet operation in civil air transportation. It could "cost" the normal traffic flow a gap of as much as 17 to 30 min., or as many as 15 or more conventional aircraft landings. Such a situation at a terminal like Chicago, New York, or Washington would be intolerable.

One phase of this problem concerns the need for standardization of the penetration procedure—that is, the descent from cruising altitude or 20,000 ft. to the level from which the instrument approach is started. Without such standardization, the possible variation in vertical and horizontal speeds makes it impossible either to plan accurately for entry of the jet into the common landing pattern or to permit safely several jet aircraft to be simultaneously in the process of descent and approach at practical intervals. Vertical speeds can vary from one stated requirement of 500 ft. per min. to the 7,000–8,000 ft. per min. possible in military fighter types. Forward speeds during penetration can vary from a holding pattern speed of 150 to 200 knots to as high as Mach 0.8 during at least a portion of the descent. The air speed used during the penetration has a direct effect upon the amount of airspace utilized for the maneuver and which must be reserved for it.

In many of the current penetration and approach procedures developed for turbojet aircraft, the penetration procedure merely places the aircraft in a position and at an altitude to begin a conventional instrument approach procedure. The aircraft must next proceed outbound from the station, make a procedure turn, and then commence final approach for a landing. Here, again, the potential variation in air speed can increase many times the area normally reserved for such a maneuver by conventional aircraft.

With regard to descent from cruising altitudes to make a landing at destination, there is the further problem of fuel required for a "missed approach" and the rerouting to an alternate destination. The fuel consumption rate during climb to cruising altitude makes it imperative that the weather and other factors be given careful consideration prior to descent for an attempted instrument approach. With present military turbojet aircraft there is considerable emphasis on this factor, although it is highly probable that this will not be so serious a problem with future civil transports. In our experience, however, the jet aircraft is virtually committed to a landing when the penetration procedure is

executed. This requires careful preflight planning as well as a recheck of weather conditions and immediate forecasts prior to starting descent.

Proper control of instrument approaches of jet aircraft is hampered at radar-equipped locations because of the poor reflective surface of such aircraft. This is further aggravated by their operation at altitude in the area of weak or no radar return of the antenna coverage pattern of our air traffic control radars.

Operation of turbojet aircraft on and in the vicinity of the airport itself raises the possibility of a number of additional problems. Some of these are not directly related to the control of air traffic, such as the effect of noise on the surrounding communities; the blast effect of jet engines and the deterioration of airport paving due to fuel spillage; and the exhaust heat effect upon passengers, ground crews, and other aircraft. The integration of jet landings, take-offs, and taxiing into the conventional aircraft traffic flow on and about the airport raises fewer difficulties than in instrument en-route flight and approach. However, on the ground, as at low altitude, turbojet aircraft pay a severe penalty in terms of a high rate of fuel consumption for any untoward delays. This makes undesirable the current practice of aircraft taxiing out and obtaining their instrument departure clearance at the end of the runway. Although these delays, on the average, are not excessive at major terminals, the occasional 30-min. or 1-hour delay would require the turbojet to return to the ramp to replace the fuel used. The turbojet is also penalized if required to wait behind a series of conventional aircraft making ground checks of their engines and going through the pretake-off engine run-ups. The jet aircraft can normally be ready for take-off within a few seconds of taking position on the runway without other preliminaries.

The operating characteristics of the turbojet are otherwise quite compatible with conventional aircraft, being capable of traffic pattern air speeds and landing speeds similar to those of large conventional transport aircraft. The lack of the braking action of reversible propellers, the aerodynamically "clean" design, and extremely slow deceleration after landing, however, do, at this time, increase the occupancy time of the landing runway. The lack of ability to shorten materially the landing roll and the need to use the full length of the runway for roll out tend to decrease the possible landing rate and the efficiency of runway utilization. Some military jet aircraft utilize drag chutes on landing, but the necessity for releasing these chutes on the runway requires a ground crew in constant attendance for immediate recovery to prevent fouling succeeding aircraft.

At many of our airports the turbojet transport and its runway requirements will add to a growing problem wherein heavily loaded transport aircraft are limited to a single long runway—often a runway direction other than that being used for the majority of the traffic flow of smaller and shorter-haul traffic.

These are the major problem areas that have become evident in our limited experience to date. I have omitted any reference to navigation facilities or to air-ground communications. These two fields require much additional study, but there are no major problems evident as yet. Concerning navigation facilities, there is only limited experience and paper theorizing so far. In my personal experience, any expectation of help in the navigation of high-altitude jet aircraft from the low–medium frequency ranges and/or ADF is extremely limited. The unreliability and shortcomings of these aids, well known to all, are multiplied many times over at the higher altitudes. Furthermore, in addition to the known vicissitudes of the ADF and its proclivity to point out the nearest thunderstorm, the ice-particle static encountered in many cloud forms at higher altitudes leaves the ADF unusable too often to be relied upon. The VHF aids—VOR ranges and ILS—appear to offer the greatest immediate possibility. There have been some reports of cross-interference from stations on the same channel at the higher altitudes. It appears possible that some of these reports may be due to attempts to utilize such stations at too great a horizontal distance and that more careful selection of the stations to be used will alleviate this problem. Further study will be required to determine the seriousness of these reports and to investigate the alleviation of the situation, if necessary, by a variation to the frequency assignment plan for stations to be used for high-altitude navigation.

In addition, the air-ground communications field is in need of further study. The limited experience to date with flush-mounted antennae on turbojet aircraft, particularly when used for frequencies in the UHF band, indicates a need for investigation of the seriousness of reported "inverted cone-of-silence" and shielding effect caused by the changes in the aircraft's attitude.

As mentioned previously, this survey of potential problem areas is rather sketchy and based upon limited knowledge, especially as related to the use of civil turbojet transports. Similarly, discussion of possible solutions must be restricted to a broad, general treatment of the probable approach toward the solutions. Our immediate efforts are being concentrated on working out current problems in the handling of military turbojet aircraft, from which we expect to gain more authoritative knowledge.

In the realm of "priority handling" of jet aircraft, there does not appear to be any practical and acceptable approach. It is obvious that competitive air-line companies would object vigorously to the granting of unlimited priority handling to one of their number which was the first to introduce the jet transport into the air transportation field. Not only questions on the basis of advertising and other business advantage would arise but disruption of normal traffic to permit priority handling would increase the burden on other traffic far out of proportion to the number of operations so handled. It is our opinion, at least at this stage, that the turbojet will have to compete with other traffic on an equal foot-

ing, except where its capabilities will enable it to move without detriment to conventional traffic flow. This is borne out by the experience and thinking of the British, who, incidentally, have contributed much to the available knowledge on this subject.

Concerning the turbojet instrument departure climb-out, it is readily apparent that discrete jet departure paths will have to be designated separately from those used by conventional aircraft. The greater air speed of jet aircraft during climb, plus their greater potential vertical speed, make it impracticable to utilize the same departure routes used for conventional aircraft, unless, of course, there is no conventional traffic at the time. Since such departure routes would be at an angle to the normal course in congested areas, other airways and routes would be crossed, requiring close adherence to assigned altitudes when crossing other routes and some compromise with the desired "uninterrupted climb."

It is feared that the airspace above 25,000 ft. will, in the immediate future, be more crowded than those altitudes available for conventional aircraft. The military services are fast increasing their fleets of jet aircraft, and the imposition of any considerable volume of civil transport operations will readily congest those available levels. Of extreme urgency, therefore, is an intensive study of altimetry—both instrumentation and operational use thereof. The present restriction of a 2,000-ft. vertical separation minimum does not appear susceptible to reduction without careful research and development of rather rigid operational procedures, and, even then, such a program may be found necessary to prevent further increase in the present requirement. There appears to be a coincidental urgent need for improvement of the altimeter instrumentation, either through development of a new instrument or improvement of the existing equipment.

The use of constantly variable cruising levels may be, as some studies have shown, somewhat overrated when the actual fuel-saving is measured. It is apparent that the use of such cruise control methods is highly impracticable unless the flight can be conducted according to Visual Flight Rules or "at least 500 feet on top." Should this feature prove to be essential, the only readily apparent solution for full IFR operation at assigned altitudes would be a stepping-up of the cruising level to successively higher approved altitudes as the flight progresses.

The terminal area problem is by far the most difficult. It appears highly doubtful that it will be desirable or necessary to reduce the present-day Instrument Flight Rule fuel requirements for civil transport aircraft—at least, comparable requirements will be necessary in commercial turbojet air transportation. The lack of priority handling will require allowance for air traffic delays. The possibility of unexpectedly lowering weather conditions at the airport, of "lost" aircraft tying up the approach system, and of an accident or other incident closing the only available runway will make mandatory a fuel reserve for a missed approach and flight to an alternate airport. Even so, it would still be undesirable for these aircraft to descend below cruising altitude, unless there was reasonable assurance that the landing could be completed.

Holding will have to be accomplished at the higher altitudes. It is also felt that some limited delay, at an intermediate altitude during descent, will be tolerated if thereby the progress of a sequence of aircraft will not be unduly interrupted. This will permit release of a turbojet aircraft from the cruising altitude, with an interim clearance to a lower level and with the expectation that further clearance will be available at or before reaching that level.

This theory, if it proves to be sound, will vastly simplify our problem. In this light, we can see, for example, the incoming turbojet starting letdown from cruising altitude to about 20,000 ft. while still inbound to the terminal and then holding briefly, if necessary, at or above that level. The penetration descent would be made at an angle of 45° to 90° from the outbound heading of the final approach path for about 10,000 ft. of descent, followed by a turn and completion of the descent to a "holding point" used to feed the final approach path. As the aircraft started its penetration turn, the approach control facility, using radar, would start to vector the aircraft as necessary to fit into an uninterrupted landing pattern of mixed conventional and turbojet aircraft. In the absence of radar (or to take some of the workload from the radar controller), the pilot of the turbojet—like other pilots—would be assigned a time and altitude for leaving the assigned fix. The major point would be the completion of the penetration procedure at a holding (or feeder) fix and at an altitude similar to those assigned conventional aircraft, thus permitting a straight-in approach to the airport.

This is but one of many possible patterns. There is a practical variation where two or more holding patterns are used, spaced to either side of the final approach path. In such a case, the penetration descent might be made outbound, far above the landing traffic, along the localizer path, with a right or left turn into either of the holding patterns. At locations equipped with long-range radar, it will be possible for the turbojet to begin its descent at some distance before reaching the terminal area. This would permit assignment of successively lower levels as the flight approached the terminal area, with little or no delaying at these intermediate levels. This constantly lowering flight pattern would enable the turbojet to be merged into the flow of conventional aircraft and handled in a normal manner. It appears highly probable that the higher fuel consumption rate during such low-altitude operation would be at least partially overbalanced by eliminating the requirement to maintain a high altitude until over the airport before starting the lengthy penetration and approach procedure.

Such plans are not compatible with the often-stated requirement for turbojet aircraft of "an uninterrupted descent to a landing, with a 'clearance to land' on leaving 20,000 ft." However, although some slight delays

might arise should the preceding aircraft in the approach sequence not perform exactly to plan, the average delay, if any, should not exceed 5 min., and it would be an emergency situation only which could cause a delay in excess of 10 min. An important factor would be the establishment of and adherence to a standard rate of descent—preferably 3,000–5,000 ft. per min.—and a maximum "speed limit" of about 150 to 200 knots during the penetration.

In the efficient handling of turbojet aircraft at a radar-control location, it will be extremely important to be able to locate quickly and identify the radar target. Radar reflectors built into the aircraft structure may partially alleviate the weak return from turbojet aircraft (a condition common to all aircraft without propellers). However, the use of a transponder, secondary radar will be imperative for the rapid identification of such aircraft as soon as they enter the coverage of the radar and to ensure the continuous tracking and precise control which will be required. Agreement has recently been reached on the basic fundamentals of common system secondary radar, but too much emphasis cannot be placed upon the need for rapid progress toward production and use of these units of this type of aircraft.

The airport operating problems appear to be somewhat easier of solution—that is, except for "noise nuisance." This problem is extremely serious with conventional aircraft and, because of the "new sound," can be expected to be even more serious with turbojet aircraft, at least in the beginning. Much work is being done in this field—far too much for me to cover here; however, principles similar to those being used with conventional aircraft will apply. Similarly, considerable research is being done in the field of blast damage to airport surfaces. As far as the exhaust heat effect on personnel is concerned, I can speak from personal experience. Within the past few weeks, I was "cornered" by the exhaust blast from a T-33 with a stuck nosewheel for a period of 4 to 6 min. at a distance of less than 50 ft. The pilot was using 65 to 85 per cent power, and, although it was uncomfortable, I suffered no ill effects—didn't even get singed! Indications are that this "problem" may be somewhat overemphasized.

We are doing some work toward reducing taxiing and take-off delays, particularly in IFR weather. Delays in take-off in instrument weather can be alleviated by the pilot's filing his flight plan in advance; advising by radio when he is ready to go (before starting engines); and getting a tentative take-off time assignment, absorbing his delay at the ramp. It does require the ability to make good the assigned take-off time, which can be a problem on some airports. More attention will be needed for the problem of providing warmup aprons near the take-off ends of runways sufficient to permit several conventional aircraft to be warming up and to allow turbojet aircraft to by-pass them safely.

One last word of caution: I have tried to look on the brighter side of the overall problem. It does appear relatively simple of solution on a progressive step-by-step basis. However, we are premising our somewhat optimistic attitude on what may well be a major change in philosophy concerning the "operating requirements" of turbojet aircraft, particularly in the civil air transportation field. There is much detailed work yet to be done and much cooperative give-and-take discussion necessary before these simple-sounding solutions can become a reality.

The Napier "Eland"

(*Continued from page 51*)

the rear bearing on the propeller shaft. The accessory drive gears and bearings are lubricated by splash oil and calibrated jets.

Engine scavenging is effected by a gear-type pump, which returns the oil from the sump to the tank through a de-aerator, and oil-heated jackets on the intake casing. Both compressor and turbine gearings are independently scavenged by vane-type pumps that return the oil to the engine sump and which ensure efficient functioning during aircraft maneuvers at all altitudes.

The reduction gear chamber is vented through a centrifugal impeller-type breather that separates the oil from the air before exhausting the air to atmosphere.

Effects of Carrier Frequency Drift on Performance of Notch Networks in A.C. Servo Systems

An Analysis of Notch Networks Showing How to Free A.C. Servo Systems from Dependence on High-Precision Power Supplies

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Introduction

CARRIER-TYPE A.C. SERVOMECHANISMS employing suppressed carrier modulation are commonly stabilized by a passive notch-type network inserted in the servo-loop. This network imparts a lead angle to the modulation (or data) frequencies, thereby improving the system dynamic performance. Notch networks are preferred over induction generators (a.c. tachometers) for damping purposes in cases where it is desired to minimize servo velocity errors such as those encountered in computer applications. Since tolerances must be placed on the components of such a network as well as on the allowable frequency drift of the carrier, it is important, particularly in aircraft applications, to determine how these factors will affect the system lead angle. Furthermore, if the servo-amplifier drives the control field of a two-phase induction motor, the effects of initial field misalignment on lead angle must be considered, for it is not always possible to have a perfect 90° alignment between the main reference and the control fields.

This paper presents an exact method of analysis of a.c. notch networks which includes both the effects of carrier frequency variations and motor field misalignments. A typical notch network is analyzed in detail, and, from the results of the analysis, a more desirable network characteristic is proposed. The analysis presented here should result in a more basic understanding of the problem which may result in a material simplification of overall instrumentation. In particular, the elimination of a precision power supply alone results in an appreciable saving in weight, cost, space, and complexity and also increases the overall reliability of the system. The designer can now accurately predict the performance of a servo system that is subject to the variations discussed in the paper.

The Servo System

The system under consideration consists of the error voltage applied to the notch network which is followed by the amplifier and a two-phase induction motor. Some of the notch networks commonly in use are: the parallel T, the bridged T, and series resonant circuit. (See Fig. 1.)

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Method of Analysis

A notch network has transfer characteristics in the carrier plane as shown in Fig. 2. In the a.c. servo for a sinusoidal analysis, the error voltage may be represented in the form $\cos mt \cos \omega_c t$, where m is the modulating or data frequency and ω_c is the carrier frequency. Sobczyk has shown the effect of a linear network on this suppressed carrier voltage. The method is to expand $\cos mt \cos \omega_c t$ into the form

$$\underbrace{1/2[\cos (\omega_c + m)t}_{\text{upper side band}} + \underbrace{\cos (\omega_c - m)t]}_{\text{lower side band}}$$

Sobczyk then determines the circuit response to the upper and lower side-band frequencies and combines them to obtain the output. If A_L is the output amplitude of the network to the lower side band, ϕ_L the phase angle to the lower side band, and A_u and ϕ_u the amplitude and phase output of the network to the upper side-band frequency, then the output of the linear network in response to the input voltage $\cos mt \cos \omega_c t$ is equal to

$$E_0 = 1/2(|A_L| + |A_u|) \cos (mt + \phi_1) \cos (\omega_c t + \phi_2) + 1/2(|A_L| - |A_u|) \sin (mt + \phi_1) \sin (\omega_c t + \phi_2) \quad (1)$$

where A_L and A_u have been defined above and where $\phi_1 = (\phi_u - \phi_L)/2$ and $\phi_2 = (\phi_u + \phi_L)/2$. Calling $(|A_L| + |A_u|)/2 = A_m$ and $(|A_L| - |A_u|)/2 = A_q$, Eq. (1) becomes

$$E_0 = A_m \cos (mt + \phi_1) \cos (\omega_c t + \phi_2) + A_q \sin (mt + \phi_1) \sin (\omega_c t + \phi_2) \quad (2)$$

This solution gives a main component and a quadrature component. For the case where the carrier frequency coincides with the center frequency of the network and the network is symmetrical,

$$A_L = A_u,\ \phi_L = -\phi_u,\ A_m = A_L,\ A_q = 0,\ \phi_2 = 0,\ \phi_1 = \phi_u = -\phi_L$$

and Eq. (2) reduces to

$$E_0 = A_m \cos (mt + \phi_1) \cos \omega_c t \quad (3)$$

If now the main reference field of the motor has a voltage $kV \sin \omega_c t$ applied to it, then E_0 will produce maximum output torque of amplitude proportional to $A_m \cos (mt + \phi_1)$. The angle ϕ_1 is then the *lead*

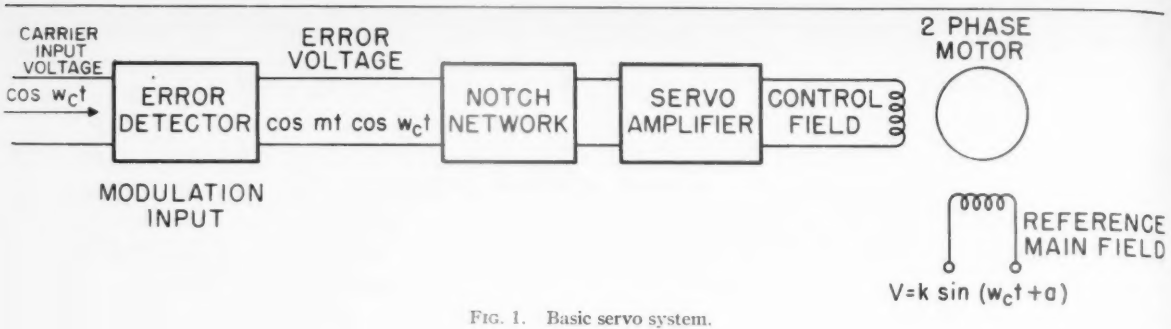

FIG. 1. Basic servo system.

FIG. 2. Notch network characteristics when carrier frequency corresponds to network center frequency.

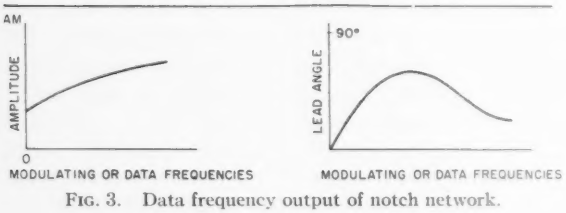

FIG. 3. Data frequency output of notch network.

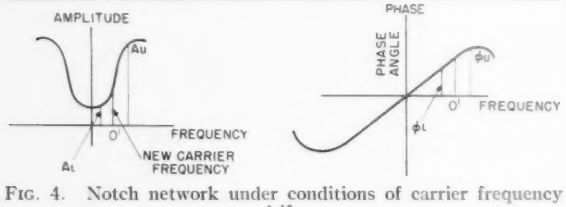

FIG. 4. Notch network under conditions of carrier frequency drift.

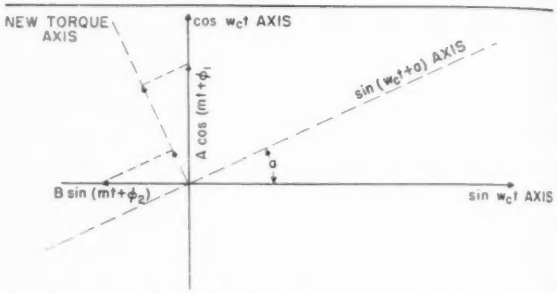

FIG. 5. Graphical solution of problem when motor misalignment is present.

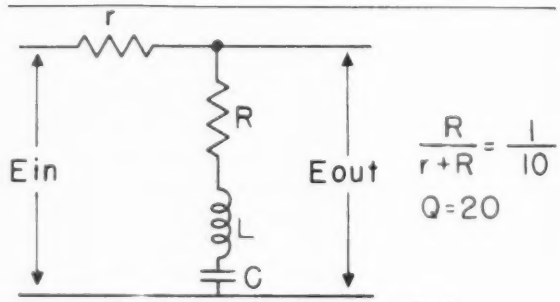

FIG. 6. 400-cycle series resonant circuit.

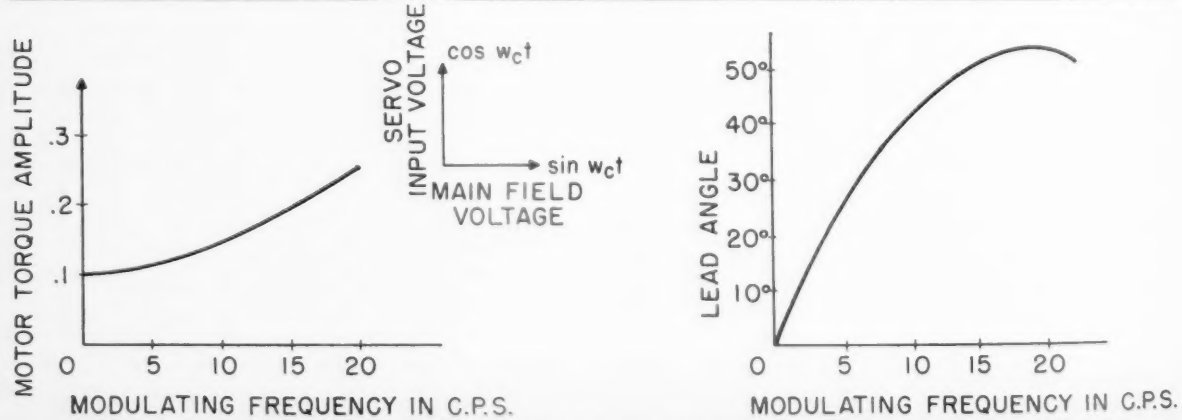

FIG. 7. Data frequency characteristics of 400-cycle circuit with motor perfectly aligned and no carrier shift.

angle for the modulating frequencies. Together with A_m, it gives the necessary information on the modulating (or data) frequencies which can be used to determine the stability and performance of the servo on a Nyquist or "log-db." plot. The fact that we get a lead angle to the data frequencies is what causes the servo to have improved stability and response. (See Fig. 3.)

This method of analysis is completely independent of whether or not the carrier frequency of the servomechanism coincides with the center frequency of the network, and hence we can evaluate the effect of carrier frequency drift. *All that is necessary is to know the amplitude and phase transfer characteristics of the network in the carrier plane.* This will then determine the amplitude and lead angle for the modulating frequencies. (See Fig. 4.)

However, if the carrier frequency shifts so that we are now operating about 0′ instead of 0, then $A_u \neq A_L$ and $\phi_u \neq -\phi_L$. Angle ϕ_2, the carrier phase shift, and the coefficient A_q will not be equal to zero. From the diagram we see that ϕ_2 and A_q depend on the modulating frequency as well as on the amount of carrier drift. If the voltage on the main field is still $kV \sin \omega_c t$, then both components of Eq. (2) will produce torque on the motor shaft. Consequently from the resolution of Eq. (2), we cannot see directly what our modulation lead angle and amplitude characteristic will be.

Effect of Carrier Drift

Our purpose is, therefore, to obtain a more useful resolution of Eq. (2) for the general case with carrier drift. Specifically, we want to resolve it into parts in which the two quadrature carrier terms do not contain any phase angles with respect to the main field. If for the input voltage $\cos mt \cos \omega_c t$ to the notch network we can express E_0 as equal to

$$A \cos (mt + \theta_1) \cos \omega_c t \pm B \sin (mt + \theta_2) \sin \omega_c t \quad (4)$$

even with carrier drift, we shall in part have solved our problem. If the main field voltage is $kV \sin \omega_c t$, only the first term in Eq. (4) will produce motor torque, assuming perfect motor demodulator action. Angle θ_1 will be the lead angle to the modulation frequencies, and A represents the amplitude characteristic. We can obtain this resolution from Eq. (2) by expanding the carrier terms into their trigonometric identities and then combining like carrier terms and simplifying the subsequent coefficients. The results are:

$$A = +\sqrt{A_m^2 \cos^2 \phi_2 + A_q^2 \sin^2 \phi_2}$$
$$B = \pm\sqrt{A_m^2 \sin^2 \phi_2 + A_q^2 \cos^2 \phi_2}$$
$$\theta_1 = \phi_1 - \alpha$$
$$\theta_2 = \phi_1 - \beta$$

where

$$\alpha = \tan^{-1} (A_q \sin \phi_2 / A_m \cos \phi_2)$$
$$\beta = \tan^{-1} (A_m \sin \phi_2 / A_q \cos \phi_2)$$

The sign of B is determined directly from our fundamental Eq. (1), varying directly with the algebraic sign of A_q. For the special case where A_q is zero, B is taken to have the positive sign. Angles α and β are always negative except for static conditions, thereby increasing the values of angles θ_1 and θ_2. The actual variations of these terms will be discussed later in connection with the specific network analysis.

Effect of Motor Field Misalignments*

When the amplifier is followed by a two-phase induction motor, the additional factor of motor field alignment must be taken into account. By the resolution of Eq. (4), we have solved the problem if the motor fields are initially perfectly aligned. It may not always be possible, however, to make the voltage on the main field 90° out of phase with the control field voltage at the center frequency. This may come about because of

* The authors are indebted to Thomas Dosch and Eugene Odin for their suggestions in connection with this topic.

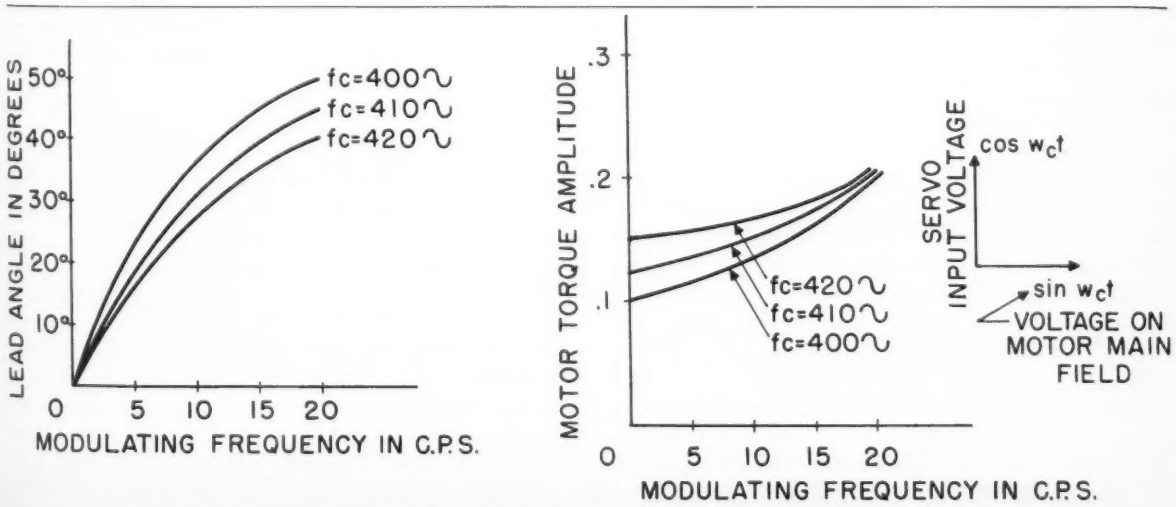

FIG. 8. Data frequency characteristics of 400-cycle circuit with carrier drift but motor field perfectly aligned.

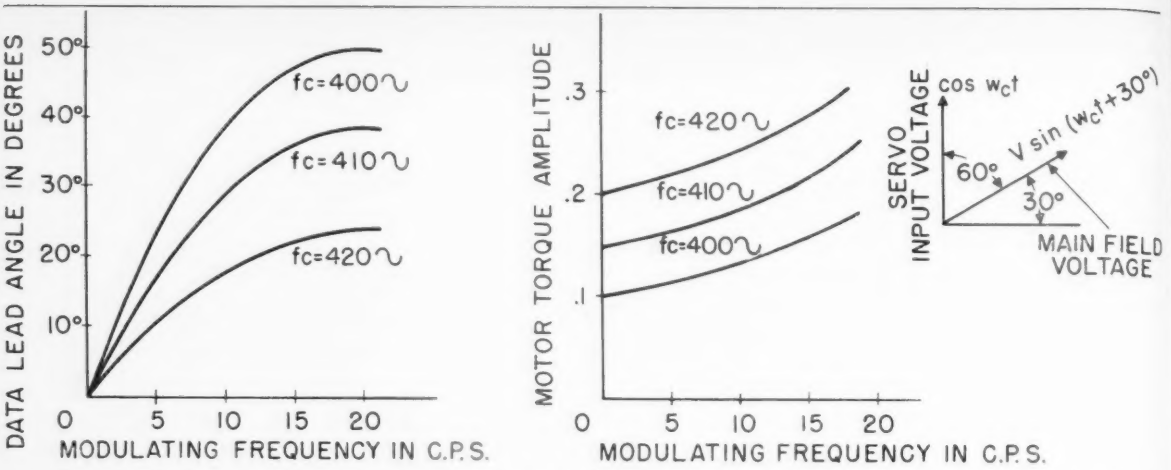

FIG. 9. Data frequency characteristics of 400-cycle circuit with carrier drift and initial motor misalignment of +30°.

carrier phase shift in the servo components themselves or through a lack of properly phased supply sources. The question arises as to what happens when the carrier frequency varies, if at the same time there is an initial motor field misalignment between the servo input voltage and the main field voltage.

In general, the voltage on the main reference field may be expressed as $kV \sin(\omega_c t + a)$. The factor k may be positive or negative depending upon the direction of rotation desired from the motor. Similarly, angle a may be positive or negative depending on whether the angle between the fields is less or greater than 90°. The object is, therefore, to resolve both components of Eq. (4) into a form having a single torque-producing component, where once again we can determine our lead angle and torque amplitude term for the data frequencies. The method of solution is as follows: The two components of Eq. (4) are first resolved along the carrier axes $\sin \omega_c t$ and $\cos \omega_c t$. (See Fig. 5.) The direction of the quadrature term depends on the algebraic sign of A_q, as shown for increasing carrier frequencies. On the diagram we draw the direction of the main field excitation. Once that is drawn and assuming that the two-phase motor rejects all in-phase voltages with respect to the main field, we have a direction perpendicular to the main field, in effect, a torque axis, on which we must project the components $A \cos(mt + \theta_1)$ and $B \sin(mt + \theta_2)$. If the main field voltage is $\pm kV \sin \omega_c t$, then only the term $A \cos(mt + \theta_1)$ will produce torque on the motor, where θ_1 is the data lead angle. For the case where $V_{\text{main field}} = V \sin(\omega_c t + a)$ and the carrier frequency increases, the torque-producing components are:

$$[A \cos(mt + \theta_1)] \cos a + [B \sin(mt + \theta_2)] \sin a = C \cos(mt + x) \quad (5)$$

The form of the resultant torque term is chosen so that C will be the amplitude of the torque term and x will be our new lead angle with motor field misalignment. If we expand both sides of the equation and collect like terms, we obtain two auxiliary equations from which we can determine C and the lead angle x. The results are as follows:

$$\tan x = \frac{A \cos a \sin \theta_1 - B \sin a \cos \theta_2}{A \cos a \cos \theta_1 + B \sin a \sin \theta_2} \quad (6)$$

Here B was chosen for the case of increasing carrier drift.

$$C^2 = A^2 \cos^2 a + B \sin^2 a + 2AB \cos a \sin a \,[\sin(\theta_2 - \theta_1)] \quad (7)$$

For the static conditions where $m = 0$, $\theta_1 = 0$, and $\theta_2 = 90$, Eq. (7) reduces to

$$C = A \cos a + B \sin a \quad (8)$$

With the aid of Eqs. (4), (6), and (7) the conditions for motor torque amplitude and lead angle for notch networks under conditions of varying carrier frequency and motor misalignment have been analyzed. If the carrier frequency is at the center of the notch network, then B will be zero, and the effect of motor misalignment is felt only in a decrease of motor torque amplitude, *not* in lead angle. When, however, the carrier frequency is shifted so that $B \neq 0$, both the modulation amplitude and lead angle characteristic are markedly changed, as will be seen.

Analysis of 400-Cycle Resonant Circuit

In order to give an order of magnitude of the various factors that influence the modulation amplitude and lead angle, a typical network will be analyzed. The notch network is a 400-cycle series resonant circuit with a Q of 20 and a 400-cycle carrier transmission ratio of one-tenth. At 400 cycles the network is slightly unsymmetrical, the lower side band being accentuated somewhat. For operation at 400 cycles and with a voltage on the main field equal to $k \sin \omega_c t$ (for 90° motor operation) the characteristic curves are as shown in Fig. 6. The amplitude characteristic rises with modulation frequency as does the lead angle. The maximum lead angle is about 53°, occurring slightly

beyond 30 cycles per sec. This network may be used with servos of natural frequencies of about 15–20 cycles. For higher natural frequencies, a lower Q should be used which extends the above curve out further, with the same maximum lead angle then occurring at a higher data frequency. For lower natural frequencies and a given transmission ratio, the Q must be higher in order to obtain the same lead angle at a lower data frequency. (See Fig. 7.)

Effect of Carrier Drift on the 400-Cycle Resonant Network

As we vary the carrier frequency above and below 400 cycles, still keeping the new carrier input voltage $\cos \omega_c t$ and the voltage on the main motor field $\sin \omega_c t$ fixed and using Eq. (4), the curves shown in Fig. 8 are obtained.

The curves for decreased carrier frequency for both amplitude and lead angle are quite similar to the ones for positive carrier drifts and are not shown for that reason.

From these curves, assuming that the two-phase motor rejects the component in phase with the main field, it appears that the lead angle and torque amplitude curves are not too seriously impaired if the carrier drifts off ± 20 cycles. There is only about a 10° loss in lead angle and a 30 per cent increase in static torque for $fc = 420$ cycles, which may not be serious. The loss in lead angle is not so great as the reduction in $(\phi_u - \phi_2)/2$ because of the presence of the angle α in the expression for resultant lead angle θ_1.

Usually a 10° loss in lead angle will not cause a servo to oscillate, provided, of course, there is a reasonable gain and phase margin. Experimentally, servos that were stabilized by such a network were still functioning properly when the carrier was shifted ± 20 cycles.

Effects of Misalignment and Carrier Drift on 400-Cycle Resonant Circuit

Considering next the case of motor field misalignment in addition to carrier frequency drift, Eqs. (6), (7), and (8) were used to determine the new lead angle and torque amplitude characteristics for misalignments of $\pm 30°$ and positive carrier drifts. (See Fig. 9.)

For the case of positive carrier drift and a 60° angle between servo input voltage and main field voltage, we see that our lead angle has dropped in half as the carrier frequency has changed by 20 cycles. The torque-producing component has practically doubled. These two factors in combination may easily cause instability of the system. As was stated previously, with field misalignment and no carrier drift, the only effect is a lowering of the torque amplitude characteristic by 13 per cent. (See Fig. 10.)

If the input servo voltage and the main field voltage are 120° apart in phase instead of 90°, the system lead angle is improved. The torque on the motor drops so much, though, that we may not have enough static torque for accuracy requirements. If the misalignment or the carrier drift is increased further, then the torque gradient may become so low as not to have servo action at all, or it may even become negative which physically means motor rotation in the opposite direction. We see that characteristics of increased torque with decreased lead angle and decreased torque with increased lead angle go together.

If the carrier frequency decreases, from Eq. (6) we see that the sign of B will change. In this case the two

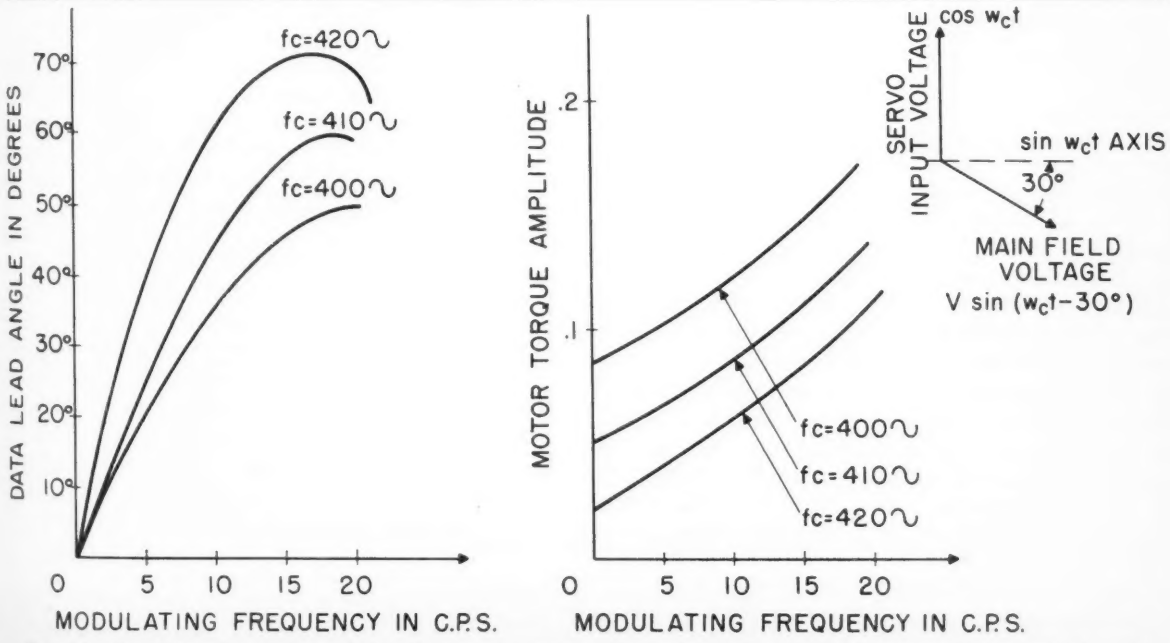

Fig. 10. Data frequency characteristics of 400-cycle circuit with carrier drift and initial motor misalignment of −30°.

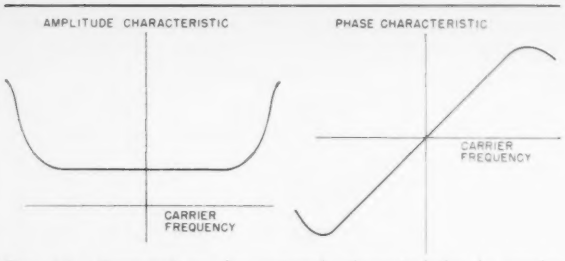

FIG. 11. Proposed passive network characteristics in carrier plane.

sets of characteristic curves will reverse; those with a 60° angle between main and control fields will show decreased motor torque and increased lead angle characteristics.

From these curves it appears that the effects of carrier drift in a.c. servos are greatly accentuated if there is misphasing of the motor fields. If the *servo input excitation voltage* and the voltage on the main field are lined up at 90° at all carrier frequencies and assuming no additional carrier phase shifts in the servo components, then shifting the carrier frequency off the notch network center frequency is not too serious. If, however, the main field is initially misaligned from the input voltage, instability due to loss in lead or extreme sloppiness due to loss in torque may result. This will depend on the degree of misalignment as well as on the amount of carrier drift. These results have been checked on servos in the laboratory.

Proposed Solutions to the Problem

As has been shown, the notch network can be used with carrier drifts, provided that the motor fields are not too severely misaligned. Looking at Eq. (6) for the lead angle with misalignment, we see that if the quadrature component is eliminated, then the lead angle would be independent of the misalignment angle a. The factor B is equal to $\sqrt{A_m^2 \sin^2 \phi_2 + A_q^2 \cos^2 \phi_2}$.

This will always be equal to zero if the network is symmetrical about the carrier frequency, making coefficients ϕ_2 and A_q equal to zero. Schemes have been proposed for resonant circuits that do this. One method using a saturable reactor for the inductance element is to obtain an a.c. voltage proportional to the amount of carrier frequency deviation, convert it to d.c., and feed it back to the inductance element to tune it to the new carrier frequency. This enables us to have again a symmetrical network at each new carrier frequency. In addition to requiring additional electronic equipment, this method suffers from calibration difficulties, hysteresis effects, and the fact that the Q of the coil is changed by the d.c. current. An alternative method is to vary the capacitance of the condenser by means of a reactance tube. Calibration difficulties and circuit complexity may make this impractical.

Desired Passive Network Characteristics

If we want to use a passive network the problem is more difficult. The factor B can be reduced considerably by flattening the amplitude characteristic of the network over a wide range. This makes $A_q = 0$, since $A_m = A_L$ under even varying carrier shifts. Angle θ_1 will then become greater than 90°, causing all terms in Eq. (6) to have the same sign. The signs of the two terms containing B will go together, thereby tending to keep the lead angle fairly constant. In addition to flattening out the amplitude curve, the phase shift curve should be extended and linearized over as great a range as possible. This must be done so that $(\phi_u - \phi_L)/2$ will be as constant as possible over a wide frequency range, since now the angle α, in the resultant expression for θ_1, disappears because of the fact that A_q is zero. Unfortunately, to obtain a fairly flat amplitude response may require that the slope of the phase curve be reduced which, in turn, cuts down on the lead angle at lower modulating frequencies. A compromise must then be reached between the two characteristics which provides for enough lead for the particular servo design. These characteristics of lead networks which tend to reduce the effect of motor misalignment also make for improved characteristics when the servo input voltage and the main field voltage are 90° apart. Since the phase curve is extended out further, we shall get lead for greater carrier frequency deviations, though perhaps not so much as the old network gives at the lower data frequencies. (See Fig. 11.)

Summary and Conclusions

An exact method of analysis of a.c. notch networks taking into account both carrier drift and motor field misalignment has been presented. The modulation amplitude and phase lead characteristics are completely determined from the transfer amplitude and phase curves of the network in the carrier plane.

If the servo input excitation voltage and the main reference field are aligned initially at 90° and assuming that this relationship does not change with frequency, then small variation of the carrier frequency will not materially affect the data plane characteristics of the notch network. Specifically, for the 400-cycle resonant circuit with a Q of 20, carrier variation of ±20 cycles should not cause servo instability for a properly designed servo. The effect of misalignment between main and control fields under conditions of carrier drift is much more serious and can result in marked reduction in either lead angle or motor torque.

In order to minimize the effect of motor field misalignment on lead angle, the passive notch network must have a flat amplitude characteristic and a linear phase shift curve over as great a frequency range as possible. Because a minimum lead angle is required to stabilize the servo, most often a compromise must be reached between the amplitude and phase characteristics.

Reference

[1] Sobczyk, A., *Stabilization of Carrier-Frequency Servomechanisms*, Journal of Franklin Institute, July, August, September, 1948

First Navy Jack, which unfurled the historic warning to the world in 1775—believed to have been first hoisted to the jackstaff of the ALFRED by one Lieut. John Paul Jones.

naval history is being made today

At 0955 on January 5th, one of the major events in naval aviation history took place.

It was the unveiling of the United States Navy's great new XP6M SeaMaster—Ship No. 1 and prototype of an entirely new concept in military aircraft.

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Today the top-level talk is turning to WBA... and shown here is the reason.

*WaterBased Aircraft

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IAS News

(*Continued from page 21*)

man of the NACA Subcommittee on Combustion. He has been a member of this Subcommittee since 1950.

▸ **Colonel C. H. Dolan II,** USAF (AF), has retired from the Air Force and the first of this year returned to the consulting field. Colonel Dolan, who served with the Lafayette Escadrille, was originally commissioned in 1917 in the Aviation Section of the U.S. Army's Signal Corps. At the time of his retirement, he was Air Force Plant Representative, Sperry Gyroscope Company Division of The Sperry Corporation.

▸ **Dr. R. Paul Harrington** (AF), Head, Department of Aeronautical Engineering, Rensselaer Polytechnic Institute, has been authorized to extend through next April his program of research for the ARDC Office of Scientific Research. Dr. Harrington's investigation, which has been under way since May, 1953, consists of devising a method by which the origin of turbulence in fluid flow, either in pipes or channels or on free surfaces, may be determined experimentally.

▸ **Jerome Lederer** (F), Managing Director, Flight Safety Foundation, Inc., was awarded a bronze medal for contributing to flight safety. The presentation was made on December 9 at the Royal Netherlands Aero Club in Amsterdam. This medal comes from the Aero Club-administered "Ir. G. A. von Baumhauer Fund" and is awarded "to the person who in a given period of 3 years has made the most valuable contribution either in a scientific or a practical sense to flight safety." Mr. Lederer received the bronze medal for the 1951–1954 period.

▸ **Norbert Edward Rowe** (F), Technical Director, Blackburn and General Aircraft Ltd., has been selected as President-Elect of the Royal Aeronautical Society.

▸ **Professor Maurice Roy** (F), Director General, Office National d'Études et de Recherches Aéronautiques (ONERA), was made by the French government a "Commandeur" in the order of "La Légion d'Honneur." This was done in recognition of Professor Roy's services to aviation.

▸ **Dr. Theodore von Kármán** (HF), Chairman, Advisory Group for Aeronautical Research and Development, NATO, was voted the 1954 recipient of the Wright Brothers Memorial Trophy, established by the National Aeronautic Association. The citation accompanying the award reads:

Hollingsworth Franklin Gregory, AFIAS, was promoted on last October 28 from Colonel to Brigadier General in the U.S. Air Force. General Gregory, winner of The Thurman H. Bane Award for 1943 presented by the IAS, has been Air Attaché to the American Embassy in Paris, France, since 1952.

"No other man has had a greater influence on the development of high-speed aircraft in the United States." The presentation of this trophy to Dr. von Kármán was in addition to the American Rocket Society's Astronautics Award, which he received on December 2. (See page 20.)

Members on the Move

The purpose of this section is to provide information concerning the latest affiliations of IAS members. All members are, therefore, urged to notify the News Editor of changes as soon as they occur.

Joel R. Baker, Jr. (M), Chief Engineering Test Pilot, North American Aviation, Inc. Formerly, Engineering Test Pilot, North American.

King D. Bird (M), Head, Operations Branch, 12-ft. variable-density wind tunnel, Cornell Aeronautical Laboratory. Formerly, Head, Operations Section, Wind Tunnel Department, C.A.L.

Philip G. Blenkush (M), Chief of Preliminary Design, Radioplane Company. Formerly, Project Engineer, Radioplane.

Richard A. Bond (TM), Second Lieutenant, USAF, Armament Officers School, Lowry AFB, Colo. Formerly, Research Engineer, Grumman Aircraft Engineering Corporation.

William H. Cook, Jr. (M), Chief, Technical Staff, Pilotless Aircraft Division, Boeing Airplane Company. Formerly, Senior Project Engineer, F-99 Bomarc Weapons System, Boeing.

Val Cronstedt (AF), now with Orenda Engines Limited, Subsidiary of A. V. Roe Canada Limited.

K. R. Duee, Jr. (M), Sales Manager, Safe Flight Instrument Corporation. Formerly, Aeronautical Field Engineering Manager, Resistoflex Corporation.

O. E. Esval (M), Chief Engineer, Wright Machinery Company Division of The Sperry Corporation. Formerly, with Sperry Gyroscope Company Division of The Sperry Corporation.

William L. Finley (TM), Associate Research Engineer "A," Boeing Airplane Company. Formerly, Research Scientist, Fluid Dynamics and Meteorology, U.S. Naval Radiological Defense Laboratory, San Francisco.

James C. Floyd (M), Vice-President, Engineering, Avro Aircraft Limited, Subsidiary of A. V. Roe Canada Limited. Formerly, Chief Engineer, Aircraft Division, A. V. Roe Canada.

A. P. Fontaine (AF), Director of Engineering, Bendix Aviation Corporation. Formerly, Staff Executive, Bendix.

Dr. Hans R. Friedrich (M), Dynamics Group Engineer, Convair-San Diego Division of General Dynamics Corporation. Formerly, Design Specialist, Convair-San Diego.

Dr. Fausto G. Gravalos (M), Chief, Aerophysics Group, Thieblot Aircraft Corporation. Formerly, Aerodynamics Specialist, Aircraft Gas Turbine Division, General Electric Company.

Matt Joseph Hansen (M), Electrical Engineer, Mason Electric Corporation. Formerly, Senior Engineer, Design, Electrical Section, North American Aviation, Inc.

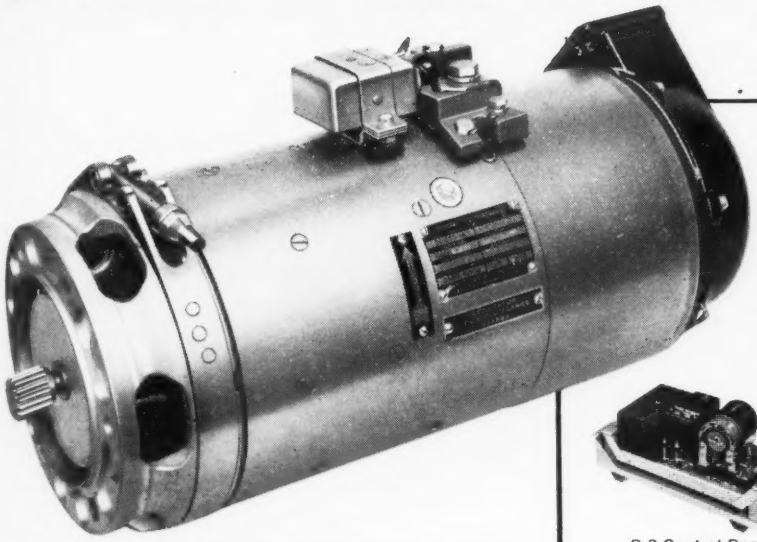
Mrs. Helen S. Marble (TM), Assistant Aeronautical Engineer, Composite Design Section, Aero-Mechanics Department, Cornell Aeronautical Laboratory, Inc. Formerly, Junior Aeronautical Engineer, Cornell Aeronautical Laboratory.

Martin Miros (TM), Junior Weights Engineer, Lockheed Aircraft Corporation. Formerly, Junior Designer, The Pelton Water Wheel Company.

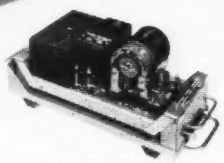
William Morse (AF), Editor, *Design Engineering*, MacLean-Hunter Publishing

Arthur Robert Teasdale, Jr., MIAS, has joined Temco Aircraft Corporation as Chief of Electronics Design. He was formerly Aerophysics Group Engineer, Convair-Fort Worth Division of General Dynamics Corporation. Since 1951, Mr. Teasdale has been a graduate lecturer in electrical engineering at Southern Methodist University.

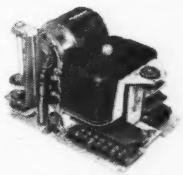
Bendix Red Bank OFFERS A COMPLETE LINE OF DC GENERATORS



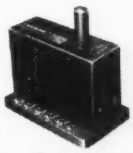
PLUS THIS PROTECTIVE AND CONTROL EQUIPMENT FOR DC SYSTEMS



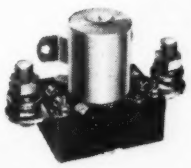
B-3 Control Panel



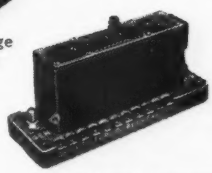
Generator Control Panel



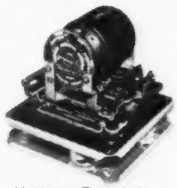
Overvoltage Protector



Line Relay



Feeder Circuit Breaker



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Type No.	Nominal Rating			Approx. Weight Lbs.	Designed to Gov't Spec.
	Amps.	Speed Range RPM	Altitude Ft		
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1345	50	4000-8500	30,000	14.25	
30E22	50	4000-8500	30,000	16.25	
30E14	75	4000-8000	25,000	24.5	N75-2RA
30E16	100	2500-4500	50,000	40	52B6588
30E20	150	4000-8000	65,000	45	
30E17	200	2870-8600	Ground Power	40	
30E07	200	3000-8000	50,000	45	AN-3632
30E18	200	4000-8000	50,000	38	MS-25009
30E19	250-350	1600-7500	Ground Power	98	
30E02	300	3450-8500	25,000	64	
30E15	300	4000-8000	50,000	50	AN-3623
30E05	400	3000-8000	50,000	68	AN-3634
30E10	400	3100-8000	60,000	67	AN-3624
30E11	500	4000-8000	50,000	75	
30E13	500	3500-8000	50,000	86	

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Company, Ltd., 481 University Ave., Toronto, Canada. Formerly, Senior Stress Engineer, A. V. Roe Canada Limited.

Dr. Parameswar Nilakantan (AF), Joint Director, Technical Development (Air), Air Headquarters Indian Air Force, F. Block, New Delhi, India. Formerly, Principal, Birla College of Science and Commerce, Pilani, Rajasthan, India.

George A. Page, Jr. (F), Vice-President—Research and Engineering, Aeronca Manufacturing Corporation. Formerly, Director of Engineering, Aeronca.

George Snyder (AF), Chief Project Engineer, Pilotless Aircraft Division, Boeing Airplane Company. Formerly, Chief, Preliminary Design, Aircraft Engineering Division, Boeing.

Robert P. Williams (TM), now Ensign, USN.

R. T. Zwack (M), Chief Design Engineer, Development and Research, Walter Kidde & Company, Inc. Formerly, Staff Engineer, Propeller Division, Curtiss-Wright Corporation.

Corporate Member News

• **Aeronca Manufacturing Corporation . . .** Industrial Research Laboratories of Baltimore, Md., has been purchased by Aeronca and is now known as the Industrial Research Laboratories Division of Aeronca Manufacturing Corporation. This Baltimore research firm is engaged in basic and applied electromechanical research. Its founder, G. Philip Stout, has been elected an Aeronca Vice-President and has been named General Manager of the new division. . . . George A. Page, Jr., FIAS, has been elected Vice-President in charge of Research and Engineering for Aeronca. He was formerly Aeronca's Director of Engineering.

• **Aircraft Radio Corporation . . .** Arrangements for sales and distribution representation in Japan and Thailand have been completed, according to a recent company announcement. The Japanese representative is C. Itoh & Company, of Tokyo. The representative in Thailand is Thai Wealth Corporation, Ltd., of Bangkok.

• **American Airlines, Inc. . . .** The tenth anniversary of American's scheduled air-freight service was celebrated last October. American's cargo capacity will be increased early in 1956 with the addition of seven Douglas DC-6A Airfreighters.

• **Bendix Aviation Corporation . . .** It was announced in late November that the first successful flight of an airplane controlled by an automatic pilot using transistors entirely instead of electron tubes took place on last May 18. The automatic pilot system is the PB-20 developed by the Eclipse-Pioneer Division and installed on the division's B-25 Flying Laboratory. A second of these completely transistorized automatic pilot systems was delivered to the Wright Air Development Center at Wright-Patterson AFB, Ohio, last April for evaluation in high-performance aircraft. It was installed in a Lockheed F-94C. Tests are being continued on both the B-25 and the F-94C. . . . The corporation recently announced that the name of Eclipse-Pioneer Foundries Division had been changed to Bendix Foundries.

• **Boeing Airplane Company . . .** The company has announced that its contract relative to the F-99 Bomarc entails the design, development, and manufacture of a new supersonic pilotless interceptor aircraft, its ground support equipment, and its guidance systems.

• **Curtiss-Wright Corporation . . .** The development of the first rocket engine in the United States which can be throttled up and down at will was recently announced by the corporation. Aside from stating that the Curtiss-Wright unit was designed and built by the Propeller Division under USAF contract, no engine details were released. This includes data relating to its size and power.

• **Douglas Aircraft Company, Inc. . . .** The name of the Military Sales Department was changed to Military Relations Department. This department has been made responsible for the administration of the Washington and Dayton offices. Donald W. Douglas, Jr., was made Vice-President—Military Relations; he had been Vice-President—Military Sales.

• **Fairchild Engine and Airplane Corporation . . .** The Board of Directors has appropriated more than $1,000,000 of company funds for an accelerated program of boundary-layer control applications to transport aircraft. Fairchild has been intensively engaged in boundary-layer control studies since 1951. The company has its own staff of engineers specializing in boundary-layer control and has contracts in effect with Mississippi State University and leading authorities at Princeton University and the University of Wichita. The Mississippi program, which has been conducted by Dr. August Raspet, MIAS, has been additionally supported by scholarship grants from Fairchild.

• **General Electric Company . . .** An advanced model jet engine, the J47-GE-33, now being produced at G-E's jet engine plant in Cincinnati, Ohio, develops 10 per cent more thrust than the early model J47-GE-17. The J47-GE-33 is completely interchangeable with the present J47-GE-17 engine, resulting in ease of changeover. . . . A new turbosupercharger, designated as CH-10, is being produced by G-E's Aircraft Accessory Turbine Department. This unit weighs 250 lbs. and, up to 25,000-ft. altitude, delivers an airflow of 220 lbs. per min. with a discharge pressure of 27.8 in. Hg absolute.

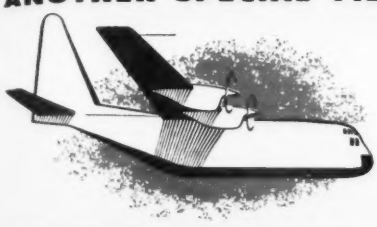
• **The Goodyear Tire & Rubber Company, Inc. . . .** A one-man helicopter, the GA-400R, has been designed by Goodyear Aircraft Corporation to serve as either a courier-liaison or tactical vehicle. It can fly at speeds up to 60 knots and has a gross weight of more than 400 lbs.

• **Jack & Heintz, Inc. . . .** The company recently announced the development of new a.c. control panels that can be readily "tailored" to the electrical system of any aircraft and which are designed to applicable USAF and USN specifications. There are four "basic" types—two for use where d.c. is available for control power and two for use where it is not. Of the two panels to be used where d.c. is available for control power, one of them is for single-generator systems (isolated), while the other is for multigenerator systems (parallel); both panels are designed to operate even if the supply of d.c. should fail. Concerning the two basic panels for operation where d.c. is not available for control power, one is for isolated systems, and the other one is for parallel systems.

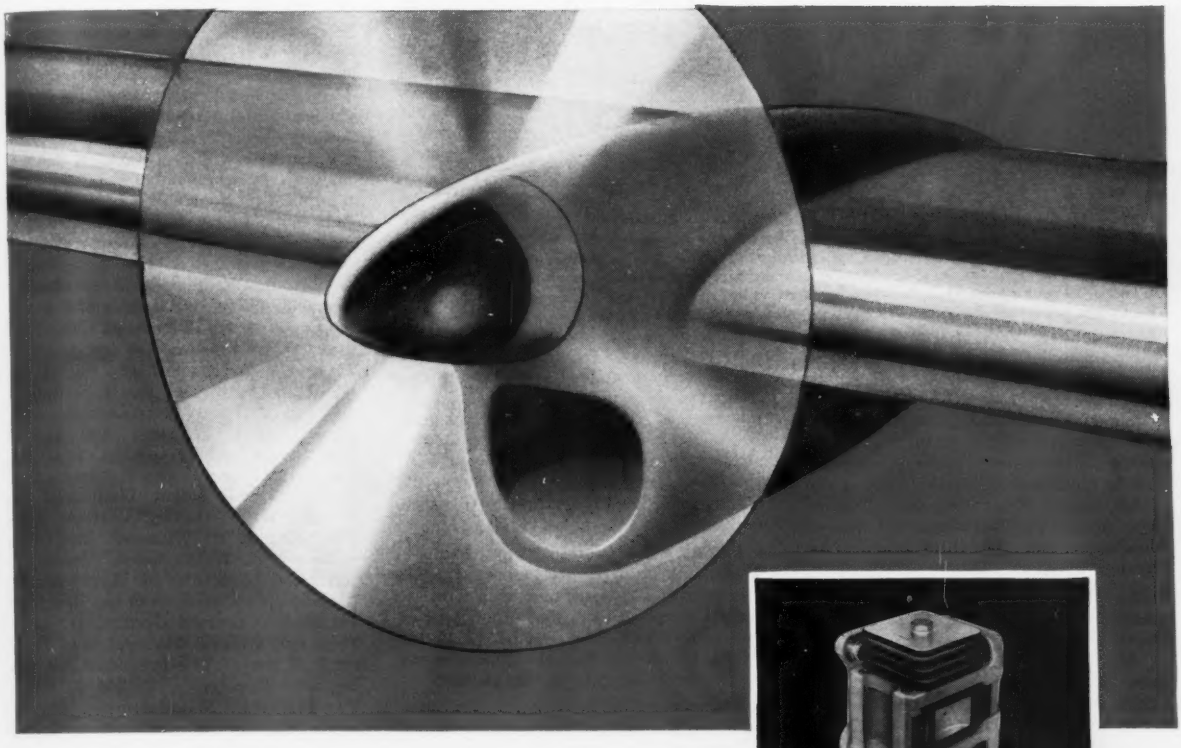
• **Lear Incorporated . . .** A new type gear-head motor designed for two-stage pump applications and designated Series 30-AR-14, has been introduced by Lear. This particular motor design is said to permit two stages of a pumping system to be driven separately by opposite ends of a single output shaft and to replace the two separate gearhead motors previously required by two-stage pumping systems. Lear engineers indicate that the new power unit is equally suitable for hydraulic pumps or air-pressurization equipment. The motor is rated at $^1/_3$ hp. continuous duty and requires 440-cycle three-phase power at either 115 volts delta or 200 volts wye. It operates at 11,000 r.p.m., with various gear trains available to match drive-shaft speed to customer requirements. . . . The LearCal Division has announced Model ADF-15A Radio Compass and Model LTR-6GH Unicom. The radio compass has a frequency coverage of three bands: 190–430 kc., 480–1,025 kc., and 1,025–1,725 kc. The unit weighs 23 lbs. complete and is available for both 12- and 24-volt electrical systems. The Unicom is a two-way VHF ground-to-air communications package that features a recently developed 10-watt crystal-controlled transmitter. Unicom's VHF receiver has a slide rule dial covering 108 to 127 megacycles; it can be calibrated precisely at the Unicom frequency 122.8 megacycles by pressing a button. . . . A 12-page booklet has been put out by the company on the Lear Vertical Gyro Indicator System.

• **Lockheed Aircraft Corporation . . .** According to a recent announcement, the U.S. Air Force is taking delivery on a new series of Super Constellation radar picket planes, designated the RC-121D. This aircraft, which has an 8,750-gal. fuel capacity, reportedly can remain aloft for more than a day. It is manned by two complete flight crews and a group of electronic specialists—up to 31 men in all. . . . Various ways of slowing down fast-landing jet planes by reverse thrust are being studied by Lockheed under a USAF contract. This general study will result in a basic manual on all known systems—delineating what system is best for what use—for the benefit of air-frame manufacturers, engine producers, and others interested in the field. . . . The name "Hercules" has been selected for the

ANOTHER SPECIAL VIBRATION PROBLEM SOLVED BY LORD



the case of the "hot turbo-prop"



The outstanding LM-200 turbo-prop aircraft engine mountings, designed and built for long, high-efficiency performance under extremely hot operating conditions.

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The Cessna Aircraft Company's new all-metal jet intermediate trainer, the XT-37, was designed for the USAF Air Training Command "to introduce the pilot to jet aircraft at an earlier phase in the training cycle." The XT-37, which features a side-by-side seating arrangement, is powered by two J-69 jet engines, manufactured by Continental Aviation and Engineering Corporation. This trainer has a range of over 700 nautical miles and a speed of over 350 m.p.h.

Lockheed C-130 turboprop military assault cargo plane.

• **Loewy Construction Company, Inc., Subsidiary of Hydropress, Inc.** . . . Three 8,000-ton extrusion presses are being built in the Loewy shops as a part of the USAF Heavy Press Program. Two of these presses are destined for Kaiser Aluminum, and the third one is for Harvey Aluminum.

• **The Glenn L. Martin Company** . . . A quantity of transition trainer aircraft, known as the B-57C, are being produced at Martin. These light bombers are being equipped with dual controls in a tandem cockpit. The B-57C will be used to provide pilots with three different types of training: (1) in night instrument flying; (2) in giving piston-engine pilots experience in jet operations; and (3) in giving fighter pilots multijet "know-how" and background. . . . A separate Nuclear Division has been established at Martin, with Tibor F. Nagey as Manager. Company plans call for the development of nuclear reactors and related compdnents for military, industrial, and commercial use.

• **Minneapolis-Honeywell Regulator Company** . . . All of the outstanding capital stock of Doelcam Corporation, Boston, Mass., has been purchased by Minneapolis-Honeywell. Doelcam manufactures precision instruments and control equipment for aircraft and industry uses. There were no managerial changes. . . . A Meritorious Safety Award was made to the company by the National Business Aircraft Association. The award was presented for having flown more than 12 years of test, research, and transportation flying without a major accident or personnel injury.

• **North American Aviation, Inc.** . . . A $5,000,000 wind tunnel for testing airplane and missile designs up to Mach 3.5 is now being constructed by North American on a 5-acre plot near Los Angeles International Airport. This facility will have a test chamber that will be 7 ft. sq. and 17 ft. long. According to the company, this will be the nation's largest intermittent blow-down type tunnel. Speeds will be produced by compressed air rushing from eight steel spheres, each with a 38-ft. diameter. The tunnel is designed for rapid conversion to speed ranges below, equal to, and above Mach 1.

• **Pan American World Airways, Inc.** . . . A simulator for the Douglas DC-7C transport has been ordered from Curtiss-Wright Corporation. Pan American has contracted for the delivery of a number of DC-7C's and will use the simulator to prepare pilots for duty on this aircraft.

• **Radioplane Company** . . . The new 28,000-sq.ft. engineering and research building brings to more than 200,000 sq.-ft. the total area now occupied by Radioplane. This building serves as office, drafting room, conference room, and electronic laboratory facilities for some 300 engineering personnel assigned to high-speed, high-altitude pilotless aircraft and guided-missile projects.

• **A. V. Roe Canada Limited** . . . Avro recently announced that two new companies had been formed and a third one had been acquired to make up a three-company operating group, with A. V. Roe Canada Limited as the parent company. (Avro Canada is, in turn, a member of the Hawker Siddeley Group.) The two new companies are Avro Aircraft Limited, formed out of Avro Canada's old Aircraft Division, and Orenda Engines Limited, formed out of the old Gas Turbine Division. The acquired company is Canadian Steel Improvement Limited, which was purchased outright from the Hawker Siddeley Group. Avro Canada's old divisions began operating under their new names on January 1, 1955. Sir Roy H. Dobson is Chairman of Avro Canada's Board of Directors, and Air Marshal W. A. Curtis is Vice-Chairman. The other directors are Crawford Gordon, Jr.; F. T. Smye; W. R. McLachlan; Sir Thomas O. M. Sopwith; Sir Frank S. Spriggs; and J. S. D. Tory. Avro Canada's senior officials are: President and General Manager, Crawford Gordon, Jr.; Vice-President (Finance) and Treasurer, A. A. Bailie; Vice-President (Industrial Relations), W. H. Dickie; Assistant to the President, A. R. Williams; and Group Secretary, H. W. Aitcheson. Senior officials and directors of Avro Aircraft Limited are: Chairman of the Board and President, Crawford Gordon, Jr.; Vice-President, General Manager, and Director, F. T. Smye; Vice-President, Engineering, and Director, J. C. Floyd, MIAS; Vice-President, Manufacturing, and Director, H. R. Smith; Vice-President, Sales and Service, and Director, J. A. Morley; Director, A. A. Bailie; Secretary

The Zero Length Launcher, shown in the accompanying photograph, was developed by The Glenn L. Martin Company and the Wright Air Development Center of the USAF Air Research and Development Command. This launching device for the Martin B-61 Matador missile can be used in any 100- by 100-ft. space. The launching equipment consists of a 39-ft. tandem-axle semitrailer weighing 35,000 lbs. without the missile, a motor generator, blower, hydraulic pump, and a wing rack. Though a self-contained unit in itself, the launcher is supported by auxiliary equipment, such as a 28-ft. 15,000-lb. transport semitrailer, a 5-ton tactical truck tractor, and a 20-ton truck-mounted crane. It was built under subcontract by Freuhauf, with Union Switch and Signal Company installing the electrical and hydraulic equipment.

and Treasurer, J. Turner; Chief Inspector and Quality Control Manager, W. Parish; Chief Test Pilot, D. H. Rogers, MIAS; and Personnel Manager, E. F. Alderton. The Directors and senior officials of Orenda Engines Limited are: Chairman of the Board and President, Crawford Gordon, Jr.; Vice-President, General Manager, and Director, W. R. McLachlan; Vice-President, Engineering, and Director, C. A. Grinyer; Vice-President, Manufacturing, and Director, E. K. Brownridge; Vice-President, Sales and Service, and Director, F. L. Trethewey; Director, A. A. Bailie; Secretary and Treasurer, K. C. Church; Chief Inspector and Quality Control Manager, L. E. Marchant; and Personnel Manager, J. E. Nesbitt. The Board of Directors of Canadian Steel Improvement Limited consists of Sir Roy H. Dobson as Chairman of the Board and H. G. Herrington as Vice-Chairman along with the following members: J. A. Wellings, Vice-President, Operations, Canadian Steel, and Sir Frank S. Spriggs, Crawford Gordon, Jr., and J. S. D. Tory.

• **Simmonds Aerocessories, Inc. . . .** Myron G. (Mike) Domsitz has been named Chief Engineer of Simmonds and will direct the company's research and development program. Mr. Domsitz was formerly Associate Director of the Diamond Ordnance Fuse Laboratory.

• **Sperry Gyroscope Company Division of The Sperry Corporation . . .** Three recently announced aircraft panel instruments, designated the Sperry Integrated Instrument System, were designed to give pilots additional and more pictorial cockpit information for flying present and future high-performance planes. These three instruments are the HZ-1 Horizon Flight Director, the C-6 Gyrosyn Compass, and the R-1 Pictorial Deviation Indicator. The HZ-1 not only tells the pilot how to move his controls to intercept and follow a desired flight path, but it also shows him his pitch and roll at all times. The C-6, the company says, gives the pilot improved radio cross bearings on a new RMI master compass dial that is free from repeater errors for greater steering accuracy during critical all-weather approaches. The R-1 portrays the ILS or VOR radio beam in miniature by means of a V-shaped bar that tells the pilot at a glance how far and in what direction he must fly to get on the beam.

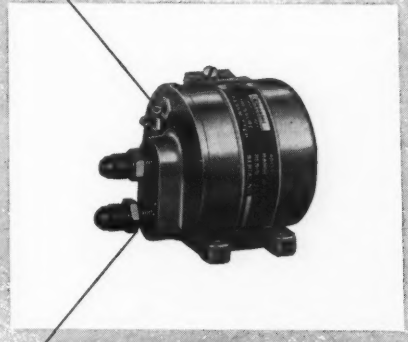
• **United Air Lines, Inc. . . .** An "Airdock," developed by United as a means of expediting loading and unloading of air liners has been successfully tested in a full-scale mock-up at the company's Denver Operating Base. It was reported that in trials with a DC-6B Mainliner the airplane was emptied of passengers and its dummy load of mail, baggage, express, and freight in only 4 min. These results are regarded by United as a rough approximation of unloading time that would be achieved under actual operating conditions. Company officials stated that on-loading with the Airdock would be greatly facilitated.

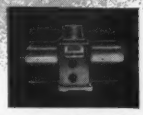
• **Vickers Incorporated, Division of The Sperry Corporation . . .** A new branch application engineering office for aircraft products in the Dallas-Fort Worth area

PRESSURE INSTRUMENTS

Giannini instruments for low pressure measurement and control utilize precision potentiometer elements to translate pressure signals into proportional electrical signals (20-50 volts) requiring little or no amplification. Models are available with single or multiple outputs and can be linear with airspeed, altitude, pressure, or to natural or empirical functions. ■ Over twenty separate and distinct types of proven capsule-powered transducers and switches are obtainable for applications requiring precise measurements of absolute, differential, or gage pressures, in ranges from ±0.5 psi diff. to 0-150 psi. ■ Instruments are available to operate under either normal military environmental conditions or under conditions of high acceleration, severe shock, and extreme vibration. *G. M. Giannini & Co. Inc. also manufactures a complete line of high pressure instruments.* Write for catalog.

MODEL 45176 illustrated 0-1 to 0-150 psi abs, diff., gage. Size 2.63 in. dia. x 3 in. weight 15 oz. max.





MODEL 45177
Up to 4 outputs and inputs in ranges 0-1 to 0-150 psi abs, diff. or gage. (Set of 2 model 45176).

MODEL 45154
Ranges 0-5 to 0-30 psi abs. Size 2.25 in. dia. x 2.48 in. weight 8 oz. max.

MODEL 45172
Ranges 0-10 to 0-30 psi abs, diff. or gage. Size 2.19 in. x 2.83 in. weight 15 oz. max.

Giannini

G. M. GIANNINI & CO., INC. • PASADENA 15, CALIF. • EAST ORANGE, NEW JERSEY

WEIGHT, POWER OR T

The Safety ball/bearing Screw can help you solve them!

EXCLUSIVE FAIL-SAFE MULTIPLE CIRCUITS
If one circuit should fail, the rest will function without interruption, sharing the load between them. In critical applications this exclusive feature has no equal.

THERE ARE OVER 30 FLIGHT-PROVED AIRCRAFT APPLICATIONS WHERE THE SAFETY b/b SCREW EXCELS

Today a remarkably efficient actuating system, old in principle but relatively new to aviation, is being rapidly adopted by aircraft engineers as the successful solution to many actuation and control problems.

Pioneered by Saginaw to reduce automobile steering effort, the *Safety ball/bearing Screw* operates at 90% to 95% efficiency—about three times that of the conventional Acme screw. Already it has been used with outstanding success by most leading aircraft builders.

ANY SIZE FROM 1½ IN. TO 39½ FT. IN LENGTH

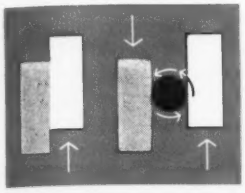
Every *Safety b/b Screw* is individually engineered for its particular application, with the wealth of know-how that only Saginaw, the pioneer, can offer. Our engineers are ready and eager to help solve your actuator problems *now*.

Safety ball bearing Screw

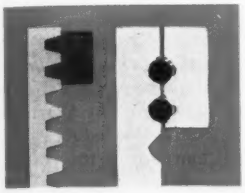
TEMPERATURE PROBLEMS?

WHAT IT IS AND HOW IT WORKS:

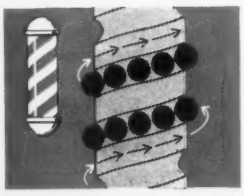
The Balls Go Round and Round and They Come Back Here!



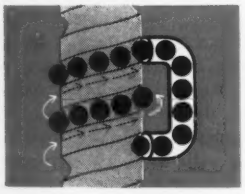
Let's start at the very beginning—with the familiar principle that there's far less friction in *rolling* than in *sliding*. The coefficient of sliding friction ranges from approximately .001 to .4—while the coefficient of rolling friction ranges from about .0005 to .003.



By applying this principle, the *Safety ball bearing Screw* radically increases the efficiency of rotary-to-linear (or linear-to-rotary) motion. Instead of *sliding* against each other, the surfaces of the screw and mating nut glide on rolling balls.

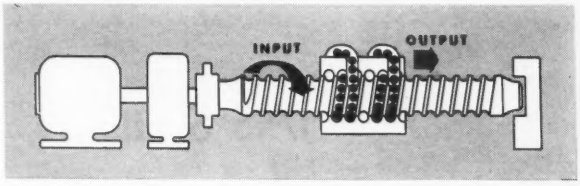


Like the stripes on a revolving barber pole, the balls travel toward the end of the nut through the spiral "tunnel" formed by the concave threads in both the nut and the screw.



At the end of their trip, one or more tubular ball guides constantly swallow the balls, lead them diagonally across the outside of the nut and back to their starting point. This forms a closed circuit through which the balls continually recirculate when the nut and screw are rotated relative to each other.

HOW IT CAN HELP SOLVE YOUR AIRCRAFT ACTUATION PROBLEMS



Compared with the conventional Acme screw's efficiency of less than 25%, the efficiency of the *Safety b/b Screw* ranges from *90% to 95%!* This makes it by far the most efficient known mechanism for translating rotary-to-linear motion, or vice versa. Combined with an electrical, hydraulic or pneumatic power source, the *Safety b/b Screw* forms an actuator with tremendous advantages for the aircraft engineer. For example, it can enable you to:

SAVE WEIGHT—compared to either Acme screw or hydraulic actuators, the *Safety b/b Screw* saves both weight and space by permitting use of smaller motors and gear boxes; eliminating pumps, accumulators, piping, etc.

SAVE POWER—by requiring only 1/3 as much torque as a conventional Acme screw for the same amount of lineal output, the *Safety b/b Screw* permits the use of much smaller motors with far less load on the electrical system.

SOLVE TEMPERATURE PROBLEMS—the *Safety b/b Screw* operates successfully at both extremely low and high temperatures, ranging from −75°F to +900°F—*without lubrication*, if necessary.

ASSURE POSITIVE POSITIONING—unlike some other types of actuators, the *Safety b/b Screw* permits precision control within thousandths of an inch, plus perfect synchronization of two or more movements.

INCREASE DEPENDABILITY—the *Safety b/b Screw* decreases combat vulnerability, offers the added security of *exclusive multiple circuits*, and reduces maintenance requirements because its "Gothic arch"-shaped races greatly decrease dirt sensitivity.

REDUCE PART AND INSTALLATION COSTS—in addition to all these design, operating and maintenance advantages, the *Safety b/b Screw* also cuts costs by permitting the use of smaller motors, decreasing power and auxiliary equipment requirements.

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(Or see our section in Sweet's Product Design File)

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has been opened at Arlington, Tex. The company reports that this office serves aircraft oil-hydraulic users in Texas and surrounding areas by providing direct engineering and product development assistance in application of hydraulic motors, pumps, and special controls.

• **Western Gear Works . . .** A 0.7-hp. rotary actuator was recently announced by Western Gear. It is a 200-volt 400-cycle 3-phase unit. Locked rotor torque is 12 lbs. with 11,200 r.p.m. input and 38 r.p.m. output and 7-amp. continuous duty. It can be rotated 330°, plus or minus 2°, in either direction. . . . Western Gear's President, Thomas J. Bannan, was awarded a special commendation from the U.S. Navy for "outstanding work in conceiving, designing and building what was termed a revolutionary oceanic submarine cable laying apparatus" installed on the U.S.S. "Neptune," reportedly the world's most modern cable-laying ship. This cable-laying machinery constructed by Western Gear solved the problem of paying out miles and miles of cable at sea with finger-tip precision, maintaining a required balance of tension and speed without damage to the cable itself.

IAS Sections

Baltimore Section

Raymond D. Blakeslee, *Secretary*

The fifty-third meeting of the Baltimore Section of the Institute of the Aeronautical Sciences was held in Maryland Hall at The Johns Hopkins University on Thursday, October 28, at 8:30 p.m. The meeting was attended by approximately 80 members and guests.

The speaker was Dr. Ellis A. Johnson, Director, Operations Research Office, Department of the Army. Dr. Johnson, while at the Naval Ordnance Laboratory early in World War II, formed the first Operations Research Group activated by U.S. forces.

Dr. Johnson introduced his subject with a description of the present status of Operations Research. With an estimated 2,000 Operations Research analysts presently employed, one-half by industry and one-half by the military, the profession is growing at the rate of 500 analysts per year. Three universities recognizing the profession are Massachusetts Institute of Technology, Case Institute of Technology, and Johns Hopkins University, all of which grant degrees in Operations Research. From 10,000 to 20,000 Operations Research analysts are envisioned within 10 years. The profession has a national society and publishes a journal; it is coming of age.

In past eras, the military had time for trial-and-error techniques. Today, this would more often amount to trial-and-catastrophe. It is, therefore, necessary that forecasted optimizations be used to aid major decisions in evaluating the plans and requirements for both military weapon systems and industry. He emphasized that there is no room for errors as the risks are too great. Continuing Operations Research analysis is required, because the objectives change with time.

The varied interests of sales, production, and research and development in modern industrial organization (this is also true of the military) make overall across-the-board planning extremely difficult. Operations Research analysis, using no new techniques but applying an objective state of mind toward optimization of operations, attempts to set up the operation analytically, integrate the individual by introducing the human factor, and play the game out.

Operations Research analysts attack these problems using such tools as analog and digital computers, linear programing, game and queing theory.

Dr. Johnson cited actual case histories from both industry and the military to emphasize the need for Operations Research in basic planning. He followed this up by recommending that Operations Research groups be part of the organization so that it can have access to information of high classification, a necessity if meaningful results are to be realized. Operations Research, he pointed out, must produce results that affect the real world and can be understood by the intended users.

After an interesting question-and-answer period, the meeting was adjourned.

Chicago Section

L. W. Sims, *Secretary*

On November 3, 31 members and guests of the Chicago Section met at 6:30 p.m. in Caffarello's Restaurant for dinner.

At 8:00 p.m., 46 members and guests assembled in the Airline Pilots Association building for the meeting, which was opened by Richard A. Schram, Chairman. Mr. Schram introduced the speaker of the evening, Chet Owen, Chief Engineer of the Grand Rapids Division, Lear Incorporated. Mr. Owen represented A. F. Haiduck, Vice-President, General Manager of the Grand Rapids Division who was unable to be present.

Mr. Owen, whose talk was entitled "Integrated Automatic Control Systems," gave a fine history of the development of aircraft flight instruments from the earliest types of air-speed indicators to the automatic pilot. He then described the current types of automatic stability augmentation systems and automatic flight control systems. He concluded his discussion with an explanation of an integrated system of automatic stability and flight controls, emphasizing the saving in weight and complexity which would result from the integration. Mr. Owen effectively illustrated his talk with slides and concluded by presenting a training film that described the operating procedures of the Lear automatic pilot and control system as installed in the F-86 airplane.

Mr. Owen generously allowed a question-and-answer period after his talk, and many questions were asked by members of the audience.

Chairman Schram closed the meeting at 10:45 p.m.

▶ On December 1, 62 members and guests met for dinner in the Commons Building at the Illinois Institute of Technology.

At 8:00 p.m., 140 members and guests assembled in the auditorium of the Chemistry Building at I.I.T. for the meeting that was opened by Chairman Schram. Mr. Schram introduced J. W. Pocock, Vice-Chairman of the Section, and Chairman of the Program Committee, who in turn introduced the speaker of the evening, Dr. Walter R. Dornberger. Dr. Dornberger, who is now Guided Missiles Specialist for the Bell Aircraft Corporation, was formerly in command of the German rocket development center at Peenemunde, where during World War II the V-1 and V-2 weapons were developed.

Dr. Dornberger, whose paper was entitled "The Rocket Powered Commercial Airliner," began his talk by briefly outlining the history of rocket development. He then set out to describe a proposed air liner, rocket powered, to carry 20 passengers. The vehicle was described as a two-stage configuration with the passenger-carrying stage mounted piggy-back fashion on the back of the booster stage, with an overall length of 90 ft., 600,000 lbs. gross weight, and developing 760,000 lbs. of thrust at take-off.

The booster stage of the air liner would exhaust its fuel supply at 80,000 ft. at which time the passenger-carrying stage would disengage itself and continue under its own power until it attains maximum speed at 150,000 ft. altitude. The booster stage, which is to be piloted, would be glided back to the take-off point. Powered flight would only be maintained for the first 4 min., with the remainder of the flight a glide. A normal landing at the destination is conceived, since the gross weight would be reduced at that time to less than 100,000 lbs., and a landing speed of 90 m.p.h. is contemplated.

Dr. Dornberger gave several sample flight schedules, such as New York to

London in 1¼ hours with a maximum speed of 8,300 m.p.h., San Francisco to Sydney, Australia, in 1½ hours with a maximum speed of 11,750 m.p.h. The cost of the fare on such a craft from New York to San Francisco was predicted as being twice that of present commercial air-line rates. Dr. Dornberger illustrated his talk with colored slides and concluded his presentation with a discussion period. Mr. Schram closed the meeting at 10:30 p.m.

Cleveland-Akron Section

Howard F. Powders, *Secretary*

The Cleveland-Akron Section of the Institute of the Aeronautical Sciences held its third meeting of the 1954–1955 season on November 23. The meeting was held at the Aircraft Division of Thompson Products, Inc., and in conjunction with the meeting a tour of the plant was offered to those attending. This tour was most interesting and gave the members in the area an opportunity to see some of the latest developments at TAPCO.

Guest speaker of the evening was Abraham Hyatt, Director, Research Division, Bureau of Aeronautics, Navy Department, Washington, D.C. Mr. Hyatt's topic was "The Highlights of the SBAC Show at Farnborough."

Mr. Hyatt, who attended the SBAC show as an official BuAer representative, illustrated his talk with slides and motion pictures made at Farnborough by Lt. Gen. Laurence C. Craigie, Commander of Allied Air Forces in Southern Europe, NATO. Mr. Hyatt's talk was both interesting and informative and gave all the members an insight into the latest developments of British aviation.

Following Mr. Hyatt's paper, A. T. Colwell, Vice-President of Thompson Products, gave a brief talk on some of the latest transportation developments here and abroad. Attendance at the meeting was good.

Dayton Section

Gunther R. Graetzer, *Secretary*

The November 16 meeting was scheduled as a joint meeting with the IAS Student Branches from the U.S Air Force Institute of Technology, The Ohio State University, and the University of Cincinnati. It attracted well over 100 persons, who heard Alfred B. Longyear speak on the "Aerobee Sounding Rocket." During the dinner at Cordell's Supper Club in Fairborn, Ohio, the Honorary Chairman, Rear Adm. T. C. Lonnquest, gave the welcome address to members and guests. Chairman George J. McTigue then introduced the speaker, who entered the rocket industry in 1946 and is now Technical

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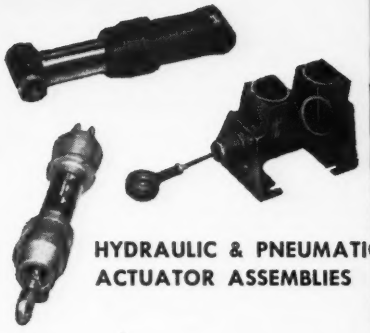
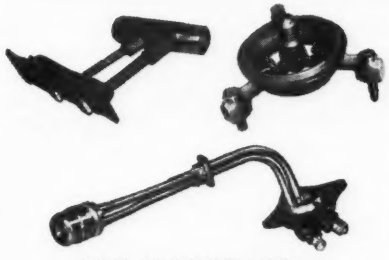
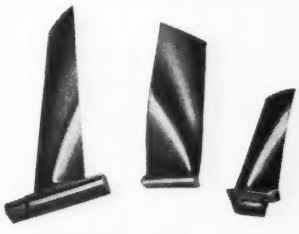
FUEL CONTROL AND METERING ASSEMBLIES



HYDRAULIC & PNEUMATIC ACTUATOR ASSEMBLIES

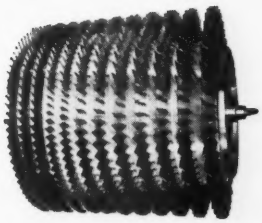


FUEL NOZZLES FOR JET ENGINES



JET ENGINE BLADES

MISCELLANEOUS AIRCRAFT AND COMMERCIAL PRECISION PARTS



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Representative of Aerojet-General Corporation's Dayton Office.

Mr. Longyear's talk is given here in abbreviated form:

"In 1946, Aerojet-General, under contract with the Navy Bureau of Ordnance, initiated development of a sounding rocket specifically designed for the purpose of carrying research instruments to altitudes of over 70 miles. The design of the Aerobee has been based upon reliability, low cost, and simplicity of maintenance of handling.

"The Aerobee is a free-flight fixed-fin stabilized vehicle powered by a bi-propellant liquid rocket, and is initially accelerated by a large JATO booster which detaches and falls away at booster burnout. The basic vehicle is 20 ft. long and 15 in. in diameter. The JATO booster adds another 6 ft. in length during initial boost. The main body is an integrally welded stainless steel tank assembly which forms the outer skin of the vehicle. The tanks contain high-pressure helium and the propellant. The helium is passed through a shutoff and regulator valve into the propellant tanks for the purpose of pumping the propellant into the thrust chamber. The thrust chamber is regeneratively fuel-cooled and operates from 34 to 44 sec., depending upon the model of the vehicle.

"Launching is accomplished from a tower approximately 150 ft. in height for initial guidance until velocity is sufficient for the fins to provide aerodynamic stability. Two towers are located in New Mexico, and a shorter unit is located on the U.S.S. 'Norton Sound' for firings over the ocean.

"Since the first launching on September 25, 1947, 124 Aerobee vehicles have been successfully flown to altitudes ranging from 34 to 100 miles, carrying payloads of scientific instruments that range in weight from 120 to 350 lbs. A new model, designated Aerobee-Hi, is currently under development by the Air Force and is expected to exceed 130 miles with a nominal payload aboard of 150 lbs.

"The Aerobee has been successfully used in upper atmosphere research with a vehicle reliability of over 94 per cent. The most broadly publicized use of the Aerobee were the flights wherein the Aero Medical Laboratory at Wright Air Development Center used the vehicles to carry live monkeys and white mice to extreme altitudes under free-fall conditions. Other sample investigations for which the Aerobee is suitable are: measurement of the earth's magnetic field; measurement of the ultraviolet and X-ray spectrum of the sun; studies of primary cosmic radiation; measurement of density, pressure, temperature, and composition of the upper atmosphere; accurate measurement of drag coefficients on supersonic missile configurations; measurement of sky brightness and light of the night sky; and development of high-altitude and high-speed parachuting techniques. It is planned that the Aerobee will be used extensively for the International Geophysical Year experiments in 1957 and 1958."

Mr. Longyear's talk was accompanied by slides and a movie. An interesting question-and-answer period brought the meeting to a close.

Hagerstown Section

A. Pickens, *Secretary-Treasurer*

The Hagerstown Section met in the Packet Room of the Terrace Restaurant on Tuesday, November 16. Sixty-three members and guests were present.

Louis Fahnestock, Director of Engineering for the Fairchild Aircraft Division, spoke on the relationship of company departments in the development of an airplane design. Briefly, Mr. Fahnestock discussed the manner in which a project starts, the reasons for strict control of engineering labor, and the duties and expectations of the various departments. A question period followed the main discussion.

Mr. Fahnestock's talk was the first of a program series intended to follow the progress of an airplane from its original conception to service. The plans for future meetings were discussed by George White, Chairman of the Program Committee.

Indianapolis Section

Paul F. Ferriera, Jr., *Secretary*

The second meeting of the Indianapolis Section was held on November 16. About 65 members and guests were present to hear Franklin W. Kolk's talk titled "The Airline Looks at the Turboprop."

Professor Paul E. Stanley, School of Aeronautics, Purdue University, acting as Chairman, welcomed the members and guests. He then introduced S. Paul Johnston, Director of the IAS, who welcomed the twenty-fourth Section into the Institute. Thomas Meskel, IAS Assistant Secretary, was then introduced. The Chairman announced that reservation cards would be sent out for the dinner-meeting and Allison Powerama exhibit on January 11, 1955. Professor Stanley then introduced Chet E. Mines, Chief of Engineering Services, Allison Division, General Motors Corporation, who introduced the speaker.

Mr. Kolk, Research and Development Engineer on the staff of M. G. Beard, Assistant Vice-President of American Airlines, Inc., presented an air line's view of three future aircraft requirements. These requirements are: (1) a long-haul four-engined turbojet passenger aircraft; (2) a short-haul four-engined turboprop passenger aircraft; and (3) a combined long-haul and short-haul turboprop cargo aircraft. Following the delivery of the paper, there was an interesting discussion on engines and automatic controls.

The talk was followed by a business meeting and the election of Section officers. The officers are: Chairman, Ephraim M. Howard; Vice-Chairman, Elmer F. Bruhn; Treasurer, Allen R. Stokke; and Secretary, Paul F. Ferreira, Jr.

Mr. Johnston and Mr. Meskel both answered questions about membership in the IAS which were asked before and after the meeting.

Los Angeles Section

Joseph W. Wechsler, *Secretary*

A new concept in the use of air power was expounded by Ernest G. Stout, Staff Engineer with the Convair-San Diego Division of General Dynamics Corporation, at the November 18 dinner meeting of the Los Angeles Section. The address, entitled "Bases Unlimited," was heard by 200 members and guests of the Section. Special guests included Capt. J. R. Ruhsenberger, Bureau of Aeronautics General Representative for the West Coast; Roy Elliott, Superintendent of the Technical Motion Picture Catalog, ARDC; and Richard L. Scharr, Chairman of the IAS Student Branch at Cal-Aero Technical Institute. In the absence of both the Section Chairman and Vice-Chairman, the meeting was ably presided over by Richard G. Fuller, Chairman of the Program Committee, and a special introduction of the speaker was made by Capt. Walter S. Diehl, USN (Ret.).

Mr. Stout's thesis was that the use of air power, especially in overwater, assault-type military operations, can be rendered immensely more effective and more flexible by freeing the tactical aircraft involved from dependence upon long, smooth airstrips, whether they be on land or on carriers. In order to permit carriers to leave the vicinity of a beachhead immediately after the amphibious assault, and because of the vulnerability of a highly concentrated assault force to atomic weapons, it is necessary to have tactical aircraft whose bases are easily set up and easily moved and for which there are numerous suitable locations in almost any zone of amphibious operation. A corollary to this ability to operate without the benefit of ponderous air bases is freedom from heavy harbor installations.

Having outlined this basic concept, the speaker described three aircraft

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Intended for combat at near sonic speeds, North American Aviation's FJ-4 Fury jet fighter is characterized by this wings. The carrier-based craft, first flown on October 28, 1954, relies on a new-type Pesco fuel transfer pump and three Pesco submerged fuel pumps.

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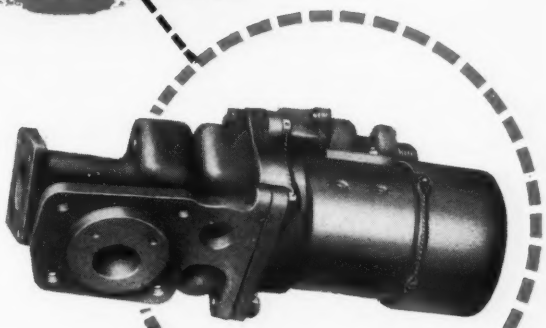
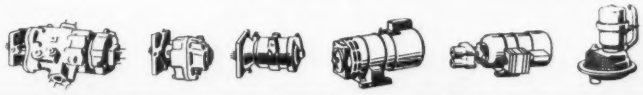


Model 122913-010 Fuel Transfer Pump was specially developed by Pesco for FJ-4. Able to pump boiling fuel, run "dry" for 15 hours and reprime itself, this pump performs a function previously considered impossible for a line-mounted aircraft fuel pump.



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that have been developed by Convair as steps in realizing this goal of air-base mobility. These are the XFY-1 Pogo, the XF2Y-1 Sea Dart, and the R3Y Tradewind. The contribution of the Pogo to this scheme is obviously its freedom from runways of any sort. Removing runways from the requirements for constructing a fighter base is a tremendous advantage to an attacking force. The Sea Dart fits into the same general scheme by using almost any body of water for its runway while having all its base and supply facilities ashore. The special design features of these two airplanes combine to give improved fighter-support capability for a vast range of land, sea, and amphibious operations. The Tradewind—especially in its R3Y-2 version, which has an LST-type nose, complete with ramps—plays the role referred to above as a corollary through its ability to bring its cargo directly from staging base to combat zone and discharge it on an open beach for the immediate use of troops in combat.

After completing his verbal presentation, Mr. Stout showed a color film of the latest flight and operational tests of all three aircraft. This included the recent successful vertical-horizontal transition flights of the XFY-1 Pogo. An interesting question period concluded the meeting.

Harold R. Sweet
Member, Program Committee

At a specialist meeting held on November 30, Dr. Isadore Rudnick, Associate Professor of Physics at U.C.L.A., spoke on "Noise from Jet Engines" before a gathering of 50 members and guests.

Dr. Rudnick outlined the four sources of jet-engine noise: aerodynamic noise from the inlet, compressor whine, coupling between the combustion chamber burning and normal modes of the engine, and jet exhaust. Although considerable difficulty is encountered in measuring noise level with present equipment, it appears that the jet exhaust is the worst offender. Inlet noise is perhaps 20 db. below that of the exhaust, and combustion chamber noise is perhaps 30 db. below. Compressor whine, once considered critical, is small enough to be disregarded.

Washington Section

R. Fabian Goranson, *Secretary*

On November 19, the Washington Section was fortunate in hearing Prof. Joseph Kaplan, Chairman of the U.S. National Committee, International Geophysical Year 1957–1958, discuss this world-wide research program. Dr. W.G. Brombacher, Honorary Chairman, in

his introduction gave much interesting background material from the late 1920's when both he and the speaker were associated with The Johns Hopkins University.

To introduce his report on the International Geophysical Year 1957–1958, Dr. Kaplan noted that in the short time he had been associated with this program it had been impossible to make an analysis in terms of the effects of the program on aviation or aeronautics. He did stress, however, that man's imagination was too limited to perceive what new discoveries might result from the observations being planned. He noted that this geophysical year was a continuation of the type of international observation conducted in 1882–1883 and again in 1932–1933, at which time they were referred to as International Polar Years. The first Polar Year was established because of the obvious need for systematic world-wide observation of geophysical phenomena and, incidentally, coincided with the discovery of the electron. He pointed out two important results from the first Polar Year observations: (1) a recognition that observations beyond the earth's atmosphere were necessary for an understanding of meteorology, and (2) an understanding that there existed a definite zone for the aurora borealis which was related to the earth's magnetic field. The second Polar Year was undertaken because a small group of leading scientists felt that it was time for a renewal of the geophysical observations. Dr. Kaplan thought it was interesting that the measurement of the ionosphere by radio pulse was accomplished about that time.

Dr. Kaplan noted that much of the technical details concerning the Geophysical Year 1957–1958 could be found in the October 1954 proceedings of the National Academy of Science. This important undertaking, he said, stemmed primarily from a suggestion by Lloyd V. Berkner at a social gathering at Silver Spring, Md. Mr. Berkner pointed out on that occasion that great advancements had been made in both theoretical and experimental fields since the last observations had been made in Polar Year 1932–1933.

The idea of an International Geophysical Year was so readily accepted by scientists that the formation of committees to proceed with plans almost came about automatically. However, Dr. Kaplan's remarks relating to the number of agencies, scientific societies, and nations involved indicated clearly the tremendous effort that had been expended by those who were promoting the project. In view of the somewhat-accepted opinion that in programs like this the wealthier nations such as the United States usually pay the bill, Dr. Kaplan noted that it was surprising how much the other 38 nations are contributing to the total effort. The period for making the observations was selected to coincide with the approach of a sunspot maximum because many geophysical phenomena are dependent on, or owe their characteristics to, the sunspot activity or concomitant solar flares and other solar disturbances.

It is readily understandable that the number of phenomena suggested for observation soon exceeded the available facilities. Accordingly, it became necessary to establish criteria for including or excluding certain observations. The criteria chosen, although not absolute, were based on the need for the particular type of information that had been suggested. Dr. Kaplan noted that eleven fields of activity comprise the program: meteorology, geomagnetism, gravity measurements, solar activity, accurate determination of latitude and longitude, glaciology, ionospheric physics, aurora and airglow, cosmic rays, oceanography, and rocket exploration of the upper atmosphere. Dr. Kaplan indicated that the most frightening thing in this program is the lack of adequately trained personnel or even personnel interested in geophysical observations.

Wichita Section

Glen S. McCormick, *Secretary*

The results of a recent election of officers of the Wichita Section are as follows: Chairman, Charles M. Seibel; Vice-Chairman, C. V. Petrie; Secretary, Glen S. McCormick; and Treasurer, Dr. John Ruptash. The representative on the Nominating Committee for the Area Council Member is Jerry Gordon.

Student Branches

The Aeronautical University

John R. Lundberg, *Secretary*

On October 8, the IAS Student Branch at The Aeronautical University held its first meeting of the 1954–1955 year. A business meeting was held at which the Secretary's and Treasurer's reports were read and approved. An announcement of the Chicago Section's October meeting was made for the benefit of any interested Student Members.

After the business meeting was concluded, several films were shown. These included Firestone Tire & Rubber Company's *How to Make a Tire*, Trans World Airline's *A Letter to a Pilot*, *Corning Center of Glass*, and *A California Vacation*.

The Student officers of this Branch are: Chairman, Dailis Grauze; Vice-Chairman, Robert Yeager; Secretary, John Lundberg; and Treasurer, Frank Anderson. The Faculty Adviser is Alfred F. Stott, Dean of Engineering.

California Institute of Technology

Gordon Fullerton
Secretary-Treasurer

The Student Branch at the California Institute of Technology held its first meeting of the school year on November 1. Robert Masterson, a Design Engineer at Aerojet-General Corporation, addressed 25 members and guests. Mr. Masterson spoke on "The Aerobee Test Vehicle." He presented several interesting design problems encountered in the construction of the Aerobee, a high-altitude research rocket, and illustrated these problems with half-scale blueprints of the rocket. Following his talk, Mr. Masterson presented a color motion picture that showed the Aerobee in action.

After registration of new members, the meeting was adjourned.

Georgia Institute of Technology

Bernard J. Dvorscak, *Secretary*

The Georgia Tech Branch was fortunate enough to be addressed by Dyke Wilmerding, Chief Flight Test Engineer, and Lyle Monkton, Chief Test Pilot, of Republic Aviation Corporation, on November 4.

Mr. Wilmerding described Republic's plant at Farmingdale and outlined the responsibilities of Flight Test Engineers. A large group of students taking design asked many questions concerning design details of the F-84. Mr. Wilmerding answered all questions that did not involve classified information.

Mr. Monkton gave a vivid description of the duties of a Production Test Pilot. He related several "sea stories" that were of particular interest to members who are also pilots and answered questions concerning the performance of the F-84.

The members feel that this was one of the most enjoyable meetings held recently. New members were enrolled at the conclusion of the meeting.

Indiana Technical College

Bernard E. Heyl, *Secretary*

The final meeting of the fall term was held on November 9 and was presided over by Chairman John B. Wright.

Ben Dow, Honorary Chairman, announced that Harold Coffman, former Chairman of the local Student Branch, had been selected as the outstanding

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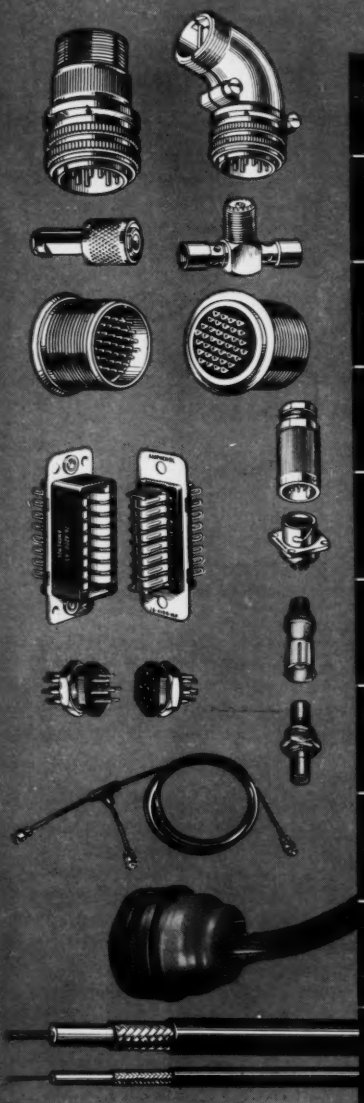

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graduating student from the Aeronautical Department of the School. The award was made on the basis of scholastic achievement and participation in extracurricular activities. An award of a Chain, School Key, and Scroll was presented to Mr. Coffman.

Mr. Dow then presented the Membership Cards and pins to 18 men who were transferred from the Associate Membership to Student Membership.

There were 35 members in attendance for the session.

The Pennsylvania State University

E. Allen Weber, *Secretary*

A regularly scheduled meeting of The Pennsylvania State University Student Branch of the IAS was held on November 10 on the Penn State campus with 60 students attending. Ralph Straley, Chairman, presided over the meeting.

Ralph A'Harrah was appointed Chairman of a committee to arrange the programs for future meetings.

The possibility of touring Piper Aircraft Corporation or a Fairchild Engine and Airplane Corporation plant was also discussed. Since a large number of the members were interested, it was decided that these companies should be contacted so that a date can be set.

A short film was then shown. Entitled *Sabre Jet*, it showed various flight attitudes of the F-86 and combat uses of the plane in Korea. The pictures taken with the gun cameras showing a MIG being shot down were also interesting.

The meeting was then adjourned, after which refreshments were served.

Polytechnic Institute of Brooklyn

Murray Rosenberg, *Secretary*

On November 30, our Branch met with the Physics Society and Math Society at Poly. Sixty persons attended. Marvin Gang, President of the Math Club, presided at this meeting. The purpose of this combined session was to discuss aspects of space travel from three standpoints; that of the mathematician, the physicist, and the aeronautical engineer. Two additional meetings will complete the series.

Murray S. Klamkin, Assistant Professor of Mathematics and Adviser of the Math Society, is a well-known instructor at the school and has the reputation for being "unstumpable"; no student has yet been able to present a legitimate and reasonable math problem that he could not do. Professor Klamkin has also shown great interest in space travel, presenting aspects of this topic in his engineering mechanics classes.

In his talk at this combined meeting, Professor Klamkin discussed the veloc-

ity of escape from earth's surface, if the projectile were to go to infinity. The approximate velocity derived was 25,000 m.p.h., neglecting air resistance. The velocities needed for different types of orbits, including circular and elliptic, were also derived.

In concluding the talk, he sketched the hyperbolic, potential barrier curve, which showed dramatically the effect of shooting missiles from orbital satellite stations.

University of Alabama

Fred Boesche, *Secretary*

The November 9 meeting of the University of Alabama Student Branch was conducted by Chairman R. M. Hollub. Speaker for the evening was F. B. Johnson, Head of the Preliminary Design Department, Georgia Division of Lockheed Aircraft Corporation. Mr. Johnson's paper was entitled "The Art of Compromise in Aircraft Design."

In summarizing a historical review of the design approach, Mr. Johnson stated that "now, in the '50's, other projects are being conceived. Not so haphazardly as in the '20's, nor so optimistically, or luckily, as in the '30's, nor with such bold faith in the organization's ability to perform, as in the '40's. In the '50's a successful project must be based on careful engineering analysis to fulfill the need that is framed within the extremely narrow limits of specification requirements."

Regarding specifications and general operational requirements, it was noted: "In order that the designer may do his best job for the customer, it is important that specifications be adequately objective. This gives the design organization opportunity to advise the customer what it costs for what he gets. It permits savings in many items of detail design which might be applied toward improving the execution of the primary objective."

The importance of optimization studies in the preliminary design process was borne out, and an example was given of airfoil section choice which included effects of thickness, Reynold's Number, flaps, and standard airfoil characteristics. "The preliminary designer makes systematic analysis of principal features of a new type. However, it must be remembered that these analyses are no better than the assumptions and data on which they are based. Fortunately, most curves of optimum characteristics have fairly flat tops. In order to make a valid optimization, it is much more important that the engineer consider all significant factors rather than be overly concerned with the precision of the data used."

Regarding compromises with production and detailed design, Mr. Johnson said, "Time to design any product is limited. If the design is started on a complex basis, time frequently runs out, and the design must be frozen without working in simplifications. If the design is started on a simplified easy-to-build basis, the task is completed within the assigned time, and there is frequently time remaining which may be used for further simplifications or weight saving. It is too frequently the case that the complex design will require considerable postprototype development to make it practical. In aircraft, simplicity cannot be overemphasized, because we usually have limited resources of time and money; the design more simply conceived is frequently the lighter, and complex design is generally more expensive to maintain. These are simple truths which most designers will admit. However, we still see unnecessary complexity. This may be assigned to (1) lazy layout; (2) temerity; (3) ignorance of source of production costs; and (4) "dreaming up horrors."

One of the most difficult compromises necessary on the part of the design engineer is that of personality. It was stated that "engineers are smarter than most people—inclined to be impatient with the views and plodding deductions of those not so gifted. Engineers must learn to compromise their own feeling of superiority in analyzing facts and figures and direct some of their mental capacity towards developing ability to analyze and understand people."

It was emphasized that schedules should not be compromised. "Engineering projects today are big business. They must be conducted on a planned schedule. This schedule is usually evolved before we know how to accomplish the job and, frequently, before it is known what is to be accomplished. Yet work to a schedule we must. To compromise this schedule affects not only the work of other groups in engineering but production, procurement, and labor load planning of the entire organization. You hear such remarks as, 'Designers are scientists. The scientist is a genius. Genius cannot be scheduled.' If we depended upon genii to design airplanes, under these circumstances, we would not get airplanes. The designer is an engineer who can apply the knowledge of the scientist and the creativeness of the genius into practical accomplishment—on schedule."

University of Illinois

John Locke, *Secretary*

The University of Illinois Student Branch of the IAS held its monthly meeting Tuesday, November 16, in the Electrical Engineering Building. Forty-seven members were present; Chairman Phil DeProtine presided at the meeting.

Our Faculty Adviser, Dr. H. H. Hilton, introduced our guest speaker, Clayton C. LaVene, Employment Manager of the Engineering Division, Douglas Aircraft Company, Inc., Santa Monica, Calif.

Mr. LaVene spoke about his experiences in flying during World War I. He was then in the Aviation Section of the U.S. Army Signal Corps and flew some of the famous airplanes of that time. He said that the engineers of the time were barely more than extremely practical mechanics. Rough sketches were made, and the product was built in a small shop. The airplane was then a sort of piecemeal construction job. Generally speaking, the builder would end up flying his first ship.

He then compared this early aircraft engineering to present-day production methods, making obvious the great advancements in techniques employed in this field. The breaking of the sound barrier, the growing importance of structures, and the need to overcome the thermal barrier were discussed successively.

Mr. LaVene then mentioned where the members of his audience might expect to begin their employment as graduate engineers. An interesting question-and-answer period followed.

Slides were shown of some of Douglas Aircraft's latest planes. Three movies, courtesy of Douglas, were shown: *Defense of America, New Wings for the Navy*, and *Exercise Test Drop*.

A short report from the Engineering Council Representative, Jerome Rachner, concluded the meeting.

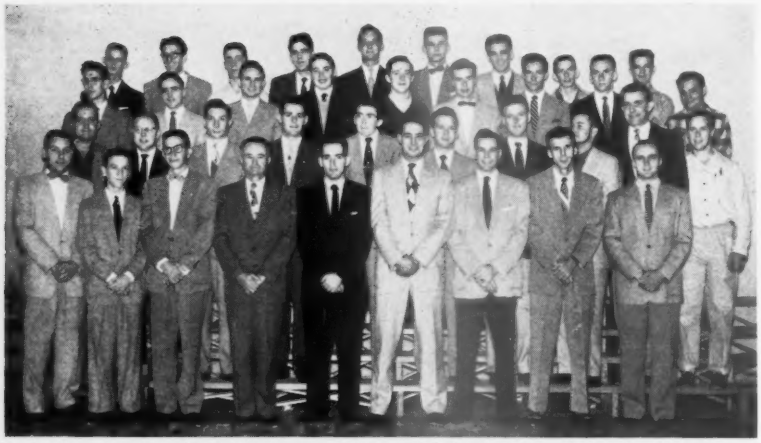
University of Kansas

Marjorie Heard, *Secretary-Treasurer*

The K.U. Student Branch held a special meeting at 7:00 p.m. on Tuesday, October 26. V. V. Schloesser, Assistant Manager of Development Engines of the Aviation Gas Turbine Division of Westinghouse Electric Corporation in Kansas City, Mo., spoke on "The Future and Development of Aircraft Jet Engines." Mr. Schloesser explained procedure of jet-engine design and types of design configurations available to the designer. His talk was illustrated with slides, and a movie, *The F4D Breaking the Speed Record*," was shown.

Students of every department of the School of Engineering were invited to this meeting, and approximately 50 persons attended. Refreshments of cider and doughnuts were served after the meeting.

▶ The University of Kansas Student Branch of the IAS held a meeting at



Shown here are the Student Members of the IAS Student Branch at the University of Oklahoma.

7:00 p.m. on November 30 Chairman John Eylar presided and introduced the speaker of the evening, Alex Petroff, Director of Research at The Cessna Aircraft Company.

Mr. Petroff devoted his talk to the application of boundary-layer control to fixed-wing aircraft. He explained how the acceleration of stagnant low-energy air on the surface of an airfoil reduces stalling speeds and gives a greater lift coefficient. Mr. Petroff illustrated his talk with a film that showed boundary-layer control on the Cessna L-19 airplane.

At the close of the meeting, the members and guests participated in a social period.

University of Oklahoma

Carroll E. Gregg, *Secretary*

Herbert F. Herndon, Branch Chairman, presided over the November 16 meeting of our branch.

Milton Green, Aerodynamics Project Engineer for Chance Vought Aircraft, Incorporated, spoke on the "Advent of the Supersonic Age." Mr. Green explained the importance of altitude in obtaining successful high-speed flight and emphasized the fact that merely exceeding Mach 1 does not necessarily mean that all of the problems of supersonic flight are solved. He went further to give an analysis of the evolution of supersonic aircraft. Also present representing Chance Vought was Guy Shehane, an Engineering Personnel Representative for the company.

The first student paper for the year was then presented by Sherrill Whitten. Mr. Whitten spoke on "Fuselage Section Properties" and explained some of the stress analysis procedures that he used while working for Douglas Aircraft Company, Inc., this past summer.

Professor L. A. Comp, Branch Faculty Adviser, then spoke to the group concerning the Annual Student Paper Competition to be held at Dallas, Texas, on April 20 for student members of IAS. A motion was made and passed that the University of Oklahoma Branch participate in this competition.

Chairman Herndon then reminded the members about open house and suggested that each member bring a project idea to the next meeting. After the meeting, the annual group picture for the "1955 Sooner Yearbook" was taken.

▶ Chairman Herbert F. Herndon presided at the December 6 meeting. Present were 61 members and guests.

The speaker was Hal M. Harrison, Supervisor—Test Engineering, Pratt & Whitney Aircraft Division of United Aircraft Corporation, whose topic was "Aircraft Gas-Turbine Engine Development Engineering." In his talk, Mr. Harrison explained the "revolution" in engineering thinking at Pratt & Whitney which was brought about by the introduction of the gas-turbine engine. He pointed out many of the obstacles that were met and overcome. He then proceeded to show that development engineering is a process of many hours of investigating, analyzing, and interpreting collected data.

Attending the meeting with Mr. Harrison and also representing Pratt & Whitney Aircraft Division was Charles E. Yenkner.

A film, *Foreign Material Ingestion in Pratt & Whitney J57-Wasp Jet Engines*, was shown to the assemblage. This film demonstrated the results of introducing ice, bolts, and various other articles into the compressor of a J57 operating at normal speeds. Damage incurred was surprisingly small.

The program was completed by entertainment provided by the members of a campus sorority, Kappa Kappa Gamma. Chairman Herndon adjourned the meeting at 8:50 p.m.

University of Virginia

W. P. Nelms, Jr., *Secretary*

The first meeting of the University of Virginia Student Branch was held in Thornton Hall on October 14. At this time, plans for the year were discussed, including proposed field trips to nearby NACA Langley Laboratory in November and to Philadelphia aircraft facilities in the spring. A motion picture on Naval aviation was shown, and refreshments were served.

▶ On November 1, 23 IAS Student Members and engineering student guests made a tour of the NACA facilities at Langley Field in the company of members of the Student Branch of Brooklyn Polytechnic Institute.

▶ A sizable group of new members were accepted at the November 11 meeting. All enjoyed the United Aircraft Corporation documentary film, *We Saw It Happen*.

Wayne University

James Hempseed, *Secretary*

On Tuesday, November 9, the Wayne University Student Branch of the IAS held its first model glider meet in the Men's Gym of the University. The gliders were of the indoor hand-launched type with a set wing area of 20 sq.in. While no world records were set, the enthusiasm and participation of both members and faculty were outstanding. All manner of wing plan forms and general layouts were in evidence.

First, second, and third prizes were awarded to: Dwight Little, average time 16.6 sec.; Joe Kochevar, 13.7 sec.; Jack Evert, 11.7 sec. The combination of sport and applied aerodynamics proved successful enough to warrant the planning of further meets in the near future.

Members Elected

The following applicants for membership or applicants for change of previous grades have been admitted since the publication of the list in the last issue of the REVIEW.

Elected to Associate Fellow Grade

Davis, Don D., Jr., M. of Ae.E., Aero. Research Scientist—Aerodynamics, Langley Aero. Lab., NACA.

Palley, I. Nevin, B.S.M.E. (Aero.), V-P—Engrg., Temco Aircraft Corp. (Dallas).

Transferred to Associate Fellow Grade

Bowman, Richard G., A.E., Asst. Chief Engr., Republic Aviation Corp.

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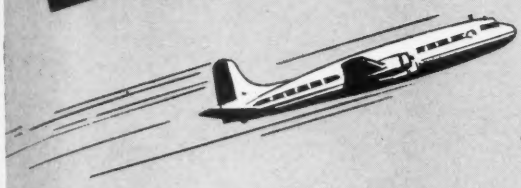

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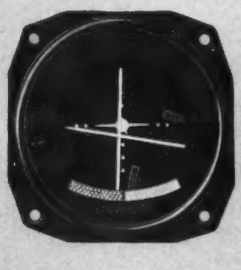

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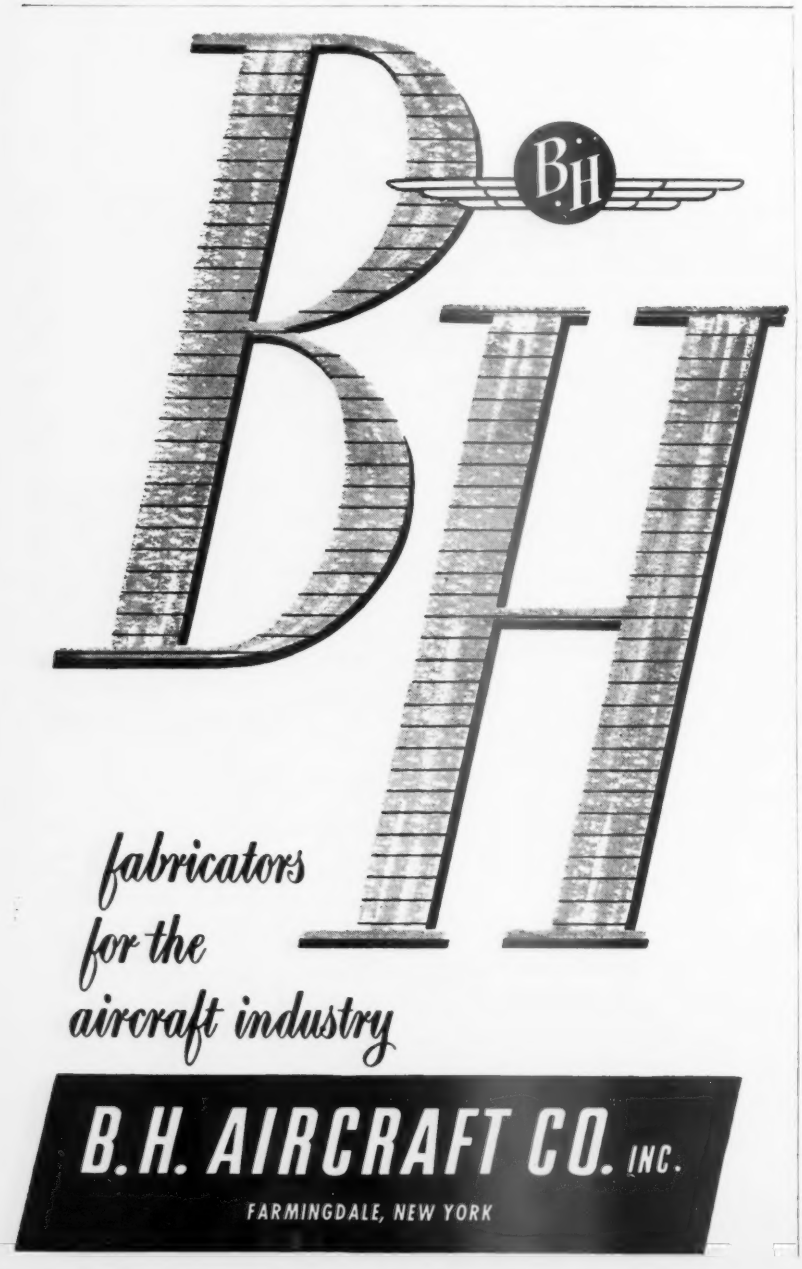

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Aerodynamics

Progress Report on Research Supported by Grants from the Defence Research Board of Canada. *U. Toronto Inst. Aerophys. Progress Rep.*, 1954–55. 67 pp. 29 refs. Includes comprehensive coverage on: Absorption and Amplification of Shock Waves; Hypersonic Studies; Boundary Layers and Heat Transfer in Supersonic Flows; Interferometric Investigation of Shock Wave Diffraction; Aerodynamic Noise.

Boundary Layer & Thermoaerodynamics

An Analytical Estimation of the Effect of Transpiration Cooling on the Heat-Transfer and Skin-Friction Characteristics of a Compressible, Turbulent Boundary Layer. Morris W. Rubesin. *U.S., NACA TN 3341*, Dec., 1954. 56 pp. 16 refs.

Boundary - Layer Transition at Mach 3.12 with and Without Single Roughness Elements. Paul F. Brinich. *U.S., NACA TN 3267*, Dec., 1954. 41 pp. 18 refs.

An Experimental Investigation of the Interaction Between Shock Waves and Boundary Layers. G. E. Gadd, D. W. Holder, and J. D. Regan. *Proc. Royal Soc. (London), Ser. A*, Nov. 9, 1954, p. 227. 33 refs. NPL Aerodynamics Div. study of the case of the formation of a boundary layer on a flat plate spanning a tunnel with the shock wave produced either externally by a wedge in the stream above the plate or from within the boundary layer by a wedge attached to the surface of the plate.

Influence of the Leading-Edge Shock Wave on the Laminar Boundary Layer at Hypersonic Speeds. Appendix—Existence of Distinct Viscous and Inviscid Flow Regions. Lester Lees. *GALCIT TR 1*, July 15, 1954. 26 pp. USAF-Army-sponsored theoretical and experimental investigation of the cases of steady flow over a semi-infinite, insulated flat plate with a sharp leading edge and with a blunt leading edge as approximated by a normal shock wave.

A Method for Analyzing the Heat Insulating Properties of the Laminar Compressible Boundary Layer. Paul A. Libby and Adrian Pallone. *J. Aero. Sci.*, Dec., 1954, p. 825. 10 refs. ONR-OAR-sponsored development as part of Project Squid of a method for obtaining an indication of variations of wall temperature when the boundary layer is laminar and two-dimensional and when there is no heat transfer downstream of the highly cooled section, with the assumptions that the flow is steady and describable by Prandtl boundary-layer equations and that the fluid be a perfect gas of a constant Prandtl Number of unity having a linear viscosity-temperature relation.

Problems of the Thermal Barrier. I—Over-All Effects. Charles H. McLellan and H. W. Adams. (*ASME Papers 54–A-57, 54–A-131.*) **II—Effects on Systems.** Alfred J. Gardner, R. B. Keusch, J. Makowski, V. L. Whitney, Jr., and R. A. McFarland. (*ASME Papers 54–A-155, 54–A-156, 54–A-206, 54–A-230.*) **III—Effects on Airframes.** N. J. Hoff, George Gerard, F. R. Steinbacher, and Louis Young. (*ASME Papers 54–A-227, 54–A-40, 54–A-100.*) *Mech. Eng.*, Dec., 1954, p. 966. Summaries of papers covering the problems of pilotless and piloted aircraft, turbojets and compressor design, propulsion installation systems, cooling requirements, lubrication, structural stresses and buckling, weight considerations, temperature-resistant materials, and related design criteria.

Similar Solutions of Compressible Boundary Layer Equations. Ting-Yi Li and H. T. Nagamatsu. *GALCIT Paper 355*, 1954. 15 pp.

Theoretical and Experimental Investigation of Aerodynamic-Heating and Isothermal Heat-Transfer Parameters on a Hemispherical Nose with Laminar Boundary Layer at Supersonic Mach Numbers. Howard A. Stine and Kent Wanlass. *U.S., NACA TN 3344*, Dec., 1954. 48 pp. 28 refs.

Thermal Conditions Associated with Aircraft in Flight. Martin Bloom. *Polytech. Inst. Bklyn. Dept. Aero. Eng & Appl. Mech., PIBAL Rep. 241*, Jan., 1954. 68 pp. 93 refs. Theoretical and experimental investigation on the rates of aerodynamic boundary-layer convective heat-transfer problems covering laminar and turbulent flows, taking into special account flows over two-dimensional flat and curved surfaces and over bodies of revolution; includes a comprehensive bibliography.

Three-Dimensional Laminar Boundary Layer with Small Cross-Flow. Artur Mager. *J. Aero. Sci.*, Dec., 1954, p. 835. 15 refs. Solution of the problem for flows over flat and curved surfaces taking into account the effect of the free steam turning on the velocity profiles in the crosswise and primary flow directions and of the asymmetric behavior of the boundary layer in the case of large surface curvatures, with detailed examples to illustrate flows occurring on the casing and in the blade fillets of turbomachinery.

Fluid Mechanics & Aerodynamic Theory

A Discussion on The First and Second Viscosities of Fluids. L. Rosenhead and others. *Proc. Royal Soc. (London), Ser. A*, Oct. 21, 1954, p. 1. 99 refs. Partial contents: The Second Coefficient of Viscosity: a Brief Review of Fundamentals, L. Rosenhead. Vorticity Generated by Sound, P. E. Doak. Acoustic Experiments Relating to the Coefficients of Viscosity of Various Liquids, E. G. Richardson. Kinetic and Thermodynamic Aspects of the Second Coefficient of Viscosity, R. O. Davies. The Two Coefficients of Viscosity for an Incompressible Fluid Containing Air Bubbles, Geoffrey Taylor. Note on the Volume Viscosity of Water Containing Bubbles, Geoffrey Taylor. Transport and Relaxation Phenomena, H. O. Kneser. On the Thermodynamic Theory of the Second Viscosity, J. Meixner. Experimental Determination of the Second Viscosity, S. M. Karim. Note on the Hydrodynamic and Thermodynamic Pressures, J. G. Oldroyd. The Present Status of the Controversy Regarding the Bulk Viscosity of Fluids, C. Trusdell.

Les Fonctions & Intégrales Elliptiques à Module Réel en Mécanique des Fluides. Robert Legendre. *France, ONERA Pub. 71*, 1954. 74 pp. 16 refs. In French. Applications of elliptical functions and integrals to the analysis of problems of fluid mechanics.

Glossary of Aeronautical Terms; Terms Used in the Dynamics of Gases. J. Rosciszewski. (*Tek. Lotnicza* [Poland], No. 5, 1953). *Gt. Brit., MOS TIB/T4406*, Sept., 1954. 10 pp. Translation.

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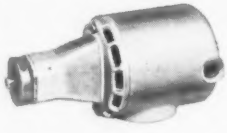

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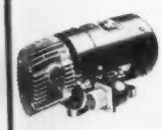

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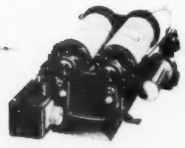

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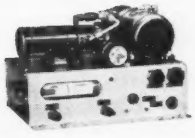

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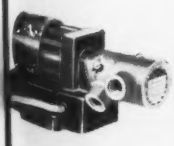

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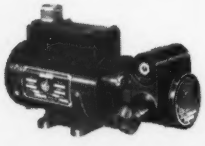

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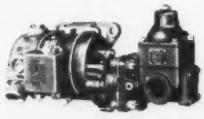

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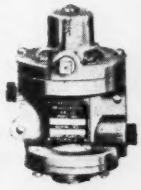

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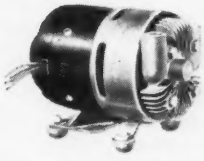

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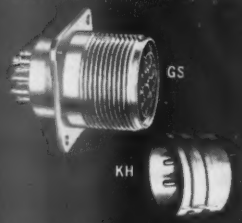

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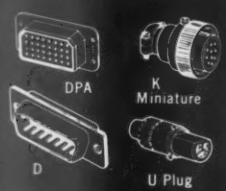

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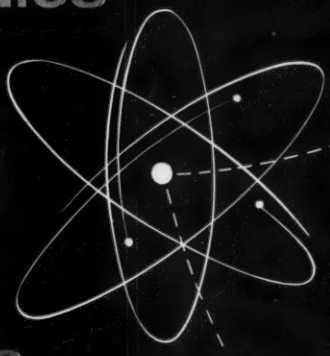

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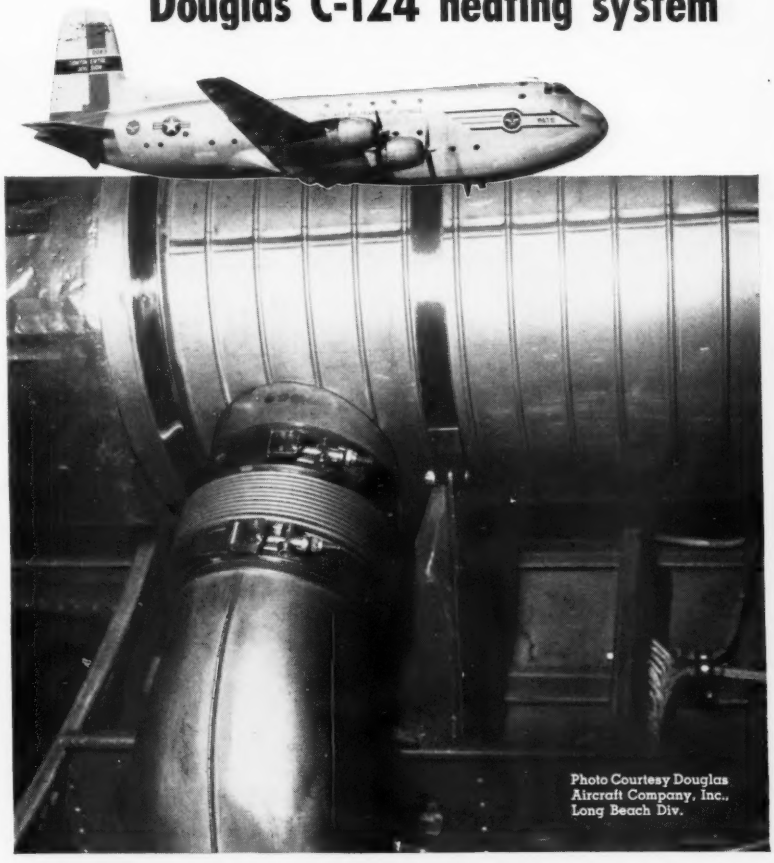

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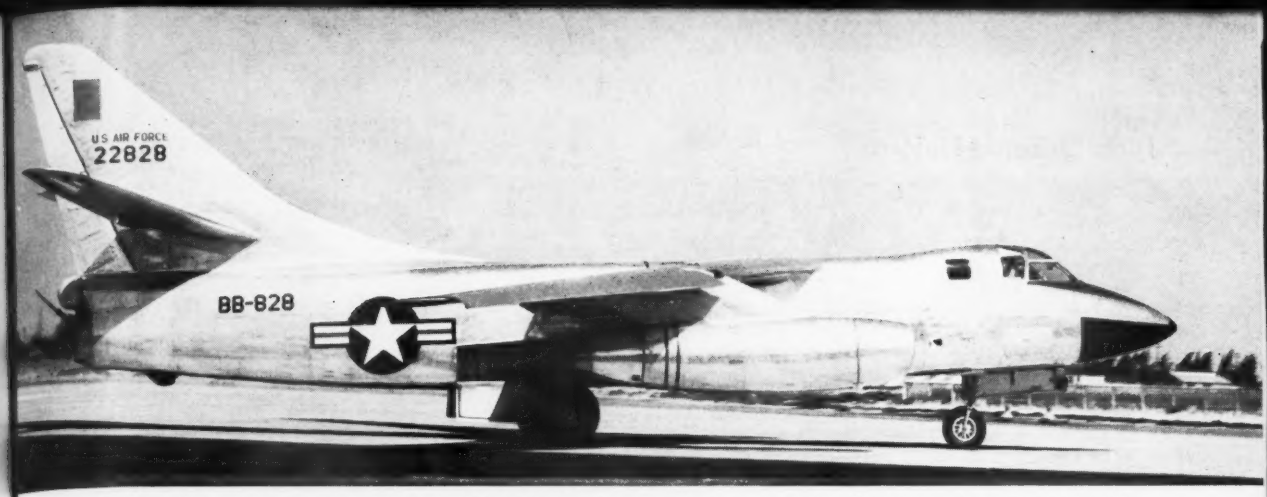


Side view of bomber shows sleek lines. It is first production aircraft to have an elevated ambient temperature a-c electric system.

Latest Air Force bomber has new G-E engineered power-generating electric system

NEW GENERAL ELECTRIC ENGINEERED SYSTEM MEETS DOUGLAS B-66 OPERATIONAL DEMANDS FOR HIGHER AMBIENT TEMPERATURES

A new a-c electric power-generating system has been developed by General Electric, and is now operating on the Air Force's newest light bomber, the Douglas B-66. The system consists of three major components: high-efficiency alternators, static voltage regulators, and generator control and protective panels.

DESIGNED FOR HIGH PERFORMANCE AIRCRAFT

With a generator that can operate at high ram-air temperatures of high speed flight, the new G-E system is designed for long life and reduced maintenance time. Its static voltage regulator has no moving components to wear out, and under laboratory testing it has withstood 5000 hours of operation without maintenance.

Regulation is preset, and requires no pilot adjustment of voltage or load division. The control panel supplies the automatic control of start-up, shut down, and maximum protection against ground fault, over and under excitation, and open phase.

SPEEDS TAKE-OFF, SPARES PILOT

The new equipment begins operating as soon as the pilot starts the engine. The system contains only two toggle switches, which may remain "on" at all times, even when a fault develops. This eliminates a series of pilot functions and sharply reduces the time required to become airborne. Under normal conditions, fault clearing and resetting are fully automatic.

SINGLE SOURCE FOR COMPLETE SYSTEMS

General Electric offers a single source for complete a-c or d-c power generating systems and constant speed drives for most aircraft. For more information, contact your nearest G-E aviation specialist, or write Section 210-92, General Electric Company, Schenectady 5, N. Y.

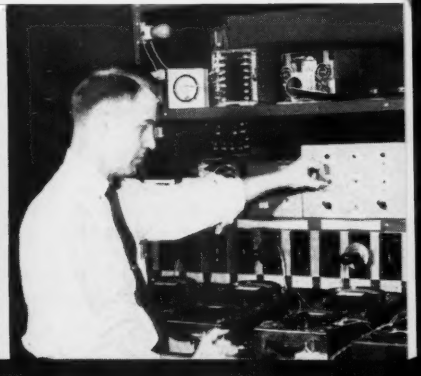
Progress Is Our Most Important Product

GENERAL ELECTRIC

Static regulator (left) maintains constant alternator output voltage. Control and protective panel (right) helps locate and isolate faulty generation.

New G-E high-efficiency a-c generator has no harmonic over 1%; produces full rating when exposed to high temperatures in high speed aircraft.

Tests of system showed better protection against over voltage, over and under excitation, ground fault, anti-cycling, difference current, and open phase.



Flight Operating Problems

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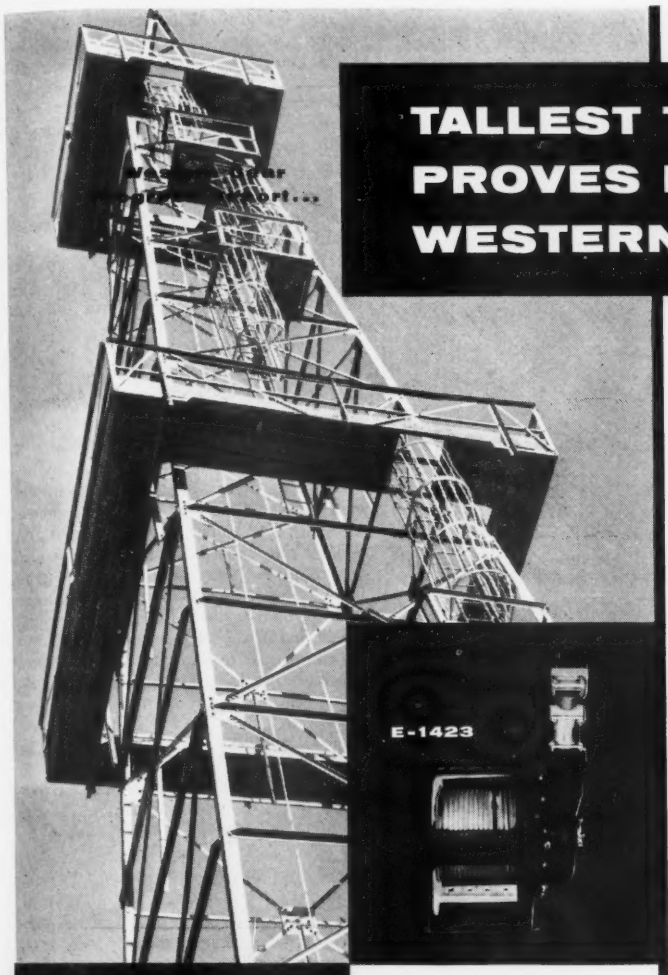
TALLEST TEST STAND PROVES RELIABILITY OF WESTERN GEAR HOISTS



One of the world's tallest aircraft hoist test stands, this 120′ tower erected at the Lynwood plant of Western Gear Works provides exact duplication of the dynamic conditions experienced on a cable at full length and on hoist mechanisms when raising and lowering specified loads. It also enables Western Gear engineers to study the regenerative motor characteristics involved during lowering. Data thus obtained provides positive information on cable up to 120′ in length, motive power and hoist mechanism itself.

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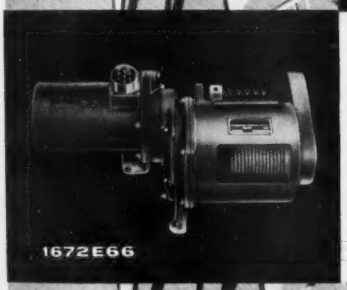

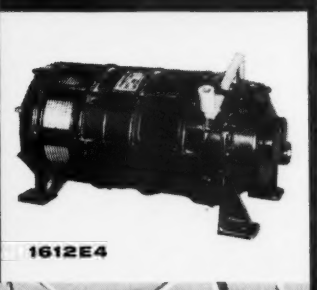

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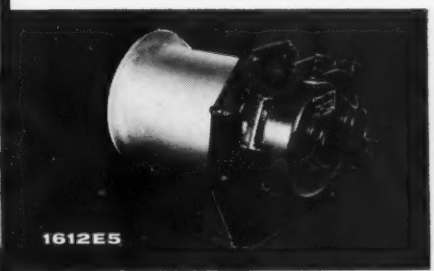

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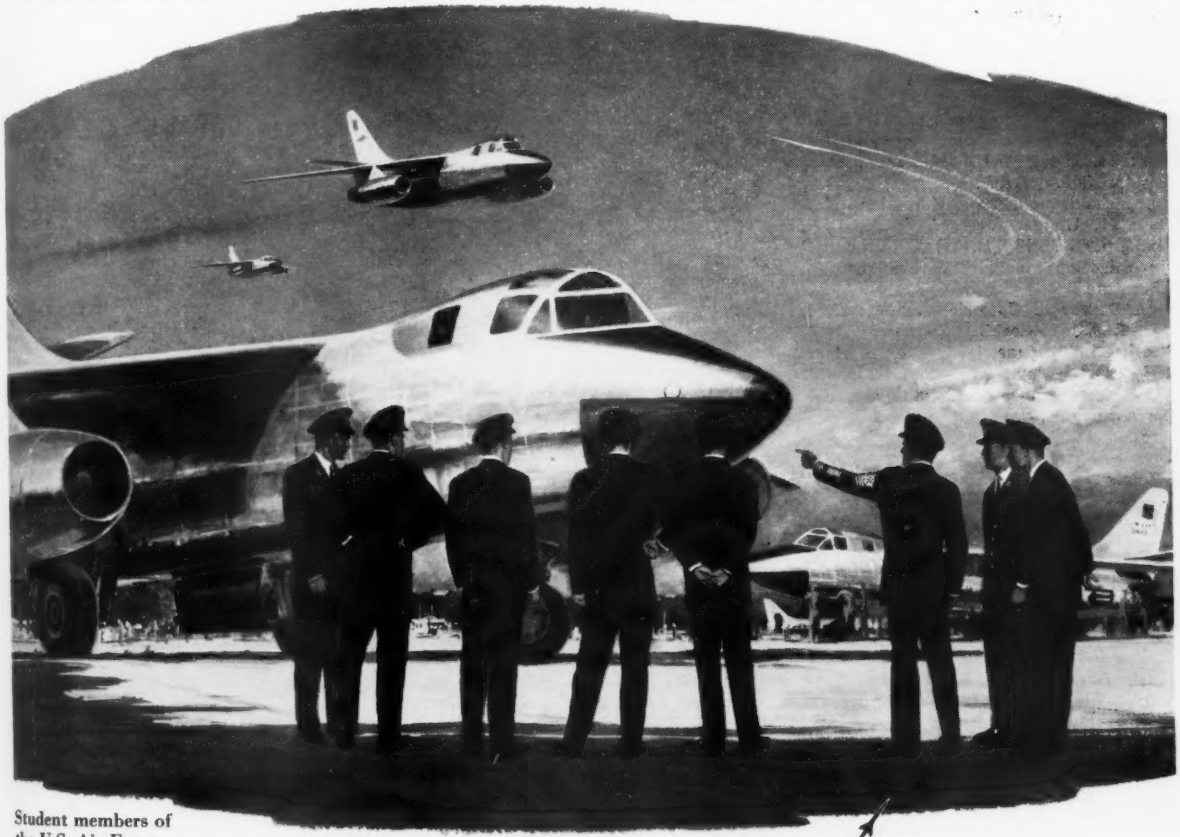
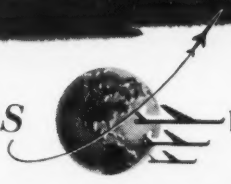


Student members of the U.S. Air Force study a Douglas RB-66

Depend on *DOUGLAS*  **First in Aviation**

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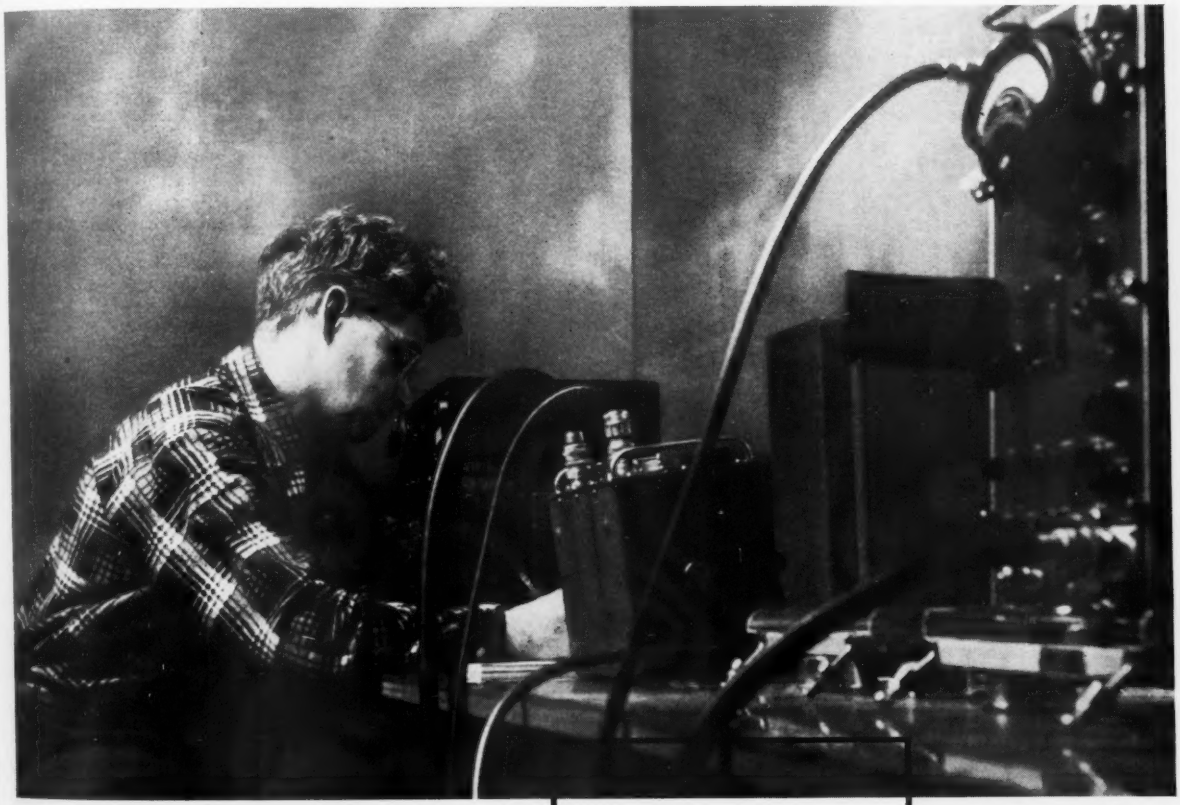

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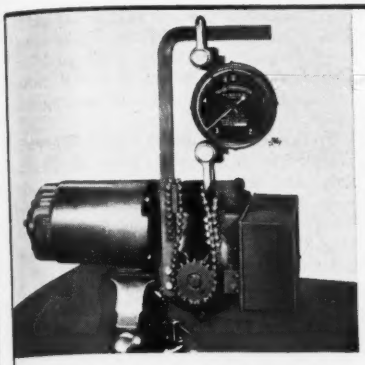

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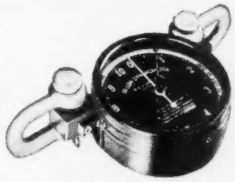

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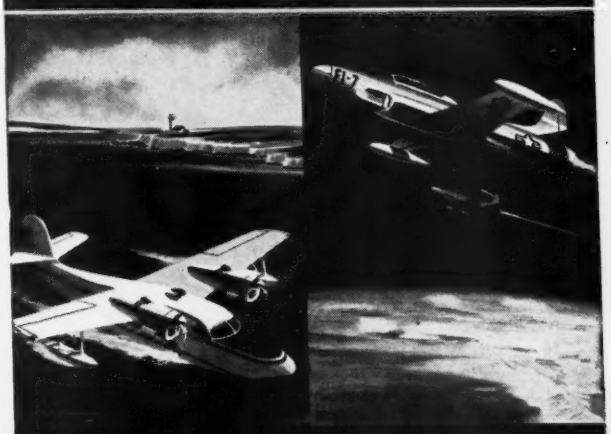

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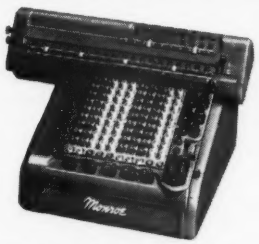

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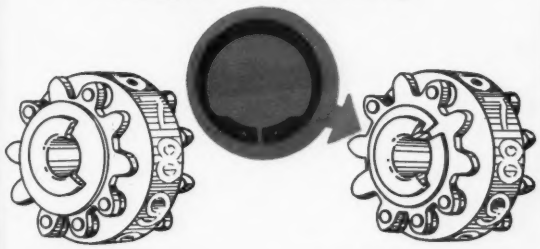

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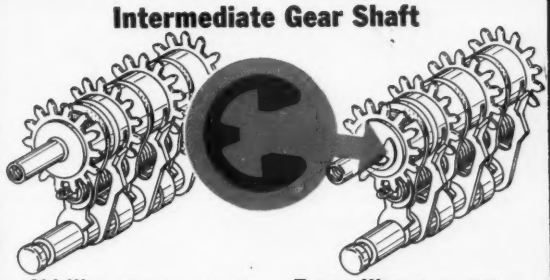

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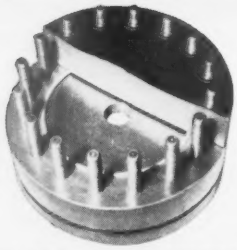

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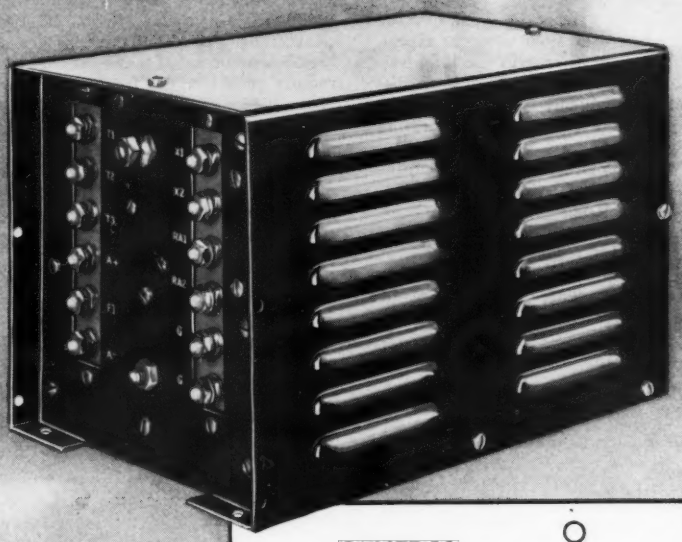

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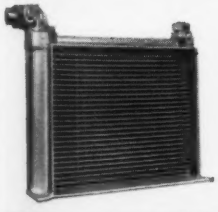

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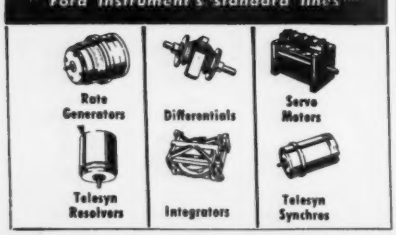

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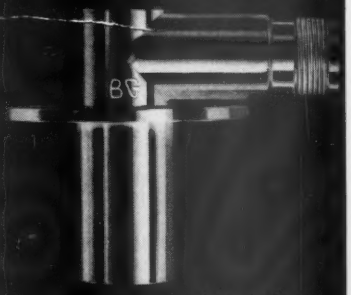

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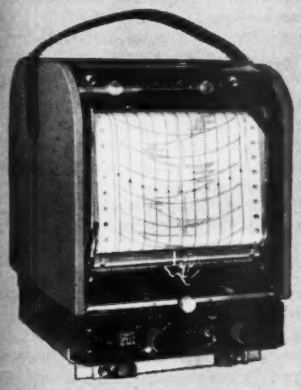

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Stress Analysis Method of Wing Structure and Application for Sweptback Wing.

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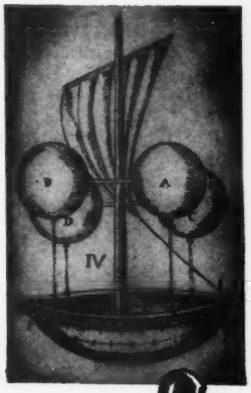

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Akinaga Katsube. *J. Japan Soc. Aero. Eng.*, Sept., 1954, p. 226. In Japanese.

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Viscosity Corrections to Cone Probes in Rarefied Supersonic Flow at a Nominal Mach Number of 4. L. Talbot. *U.S., NACA TN 3219*, Nov., 1954. 39 pp. 24 refs.

Aeronautical Reviews — BOOKS

Book Notes

AERODYNAMICS

Gas Dynamics of Thin Bodies. F. I. Frankl and E. A. Karpovich. Translated from the Russian by M. D. Friedman. New York, Interscience Publishers, Inc., 1954. 175 pp., diagrs., figs. $5.75.

This monograph, which was originally published in Russia in 1948, is intended to bring together the latest work on the formulization of the linearized problems of compressible flow theory and the methods of their solution. Chapter I contains a short historical survey and the basic formulation of the problem with a method of solving the differential equation. Chapter II treats rigorously and in detail the compressible flow around bodies of revolution. Chapter III reviews previous work on wings of infinite span in steady motion; compares linearized theory of bodies and wings; and introduces the method of Krasilshchikova, which, the translator states, was apparently derived simultaneously in this country by J. Evvard. Chapter IV treats unsteady flows and applications to the problems of supersonic propellers. Chapter V lists another method of solution, that of conical flow fields. The translator sees the book as an aid to engineers, graduate students, and applied mathematicians, and as a fine textbook for a one-year course in linear supersonic aerodynamics. At the time of preparing the translation, M. D. Friedman was associated with the Ames Aeronautical Laboratory, NACA.

Fluid Dynamics and Heat Transfer. James G. Knudsen and Donald L. Katz. (University of Michigan, Engineering Research Institute, Bulletin No. 37. September, 1953.) Ann Arbor, Michigan, University of Michigan Press, 1954. 243 pp., illus., diagrs., figs. $3.50.

This bulletin represents an attempt to bring together those phases of fluid dynamics which are fundamental to an understanding of the mechanism of convection heat transfer. Research conducted at the University of Michigan has shown that knowledge of heat transfer would profit from a complete understanding of fluid dynamics. In many instances those who are active in the field of fluid dynamics are not at the same time active in the field of heat transfer; besides, only a limited number of journals report research in both fields. The authors believe that the compilation and organization of material common to these two fields would be useful to those practicing or teaching engineering. Fluid flow in various closed conduits and around various immersed shapes is discussed from the standpoint of the flow mechanism, this mechanism involving mainly a consideration of velocity profiles and boundary layers. Equations and plots are provided which should be useful in predicting velocity profiles for the different types of flow considered. The energy losses associated with fluid flow are also discussed, and material is provided which may be used directly to predict these energy losses. Whenever possible, the attempt is made to relate the energy loss to the mechanism of flow or, conversely, to predict the energy loss from the mechanism. Finally, the process of heat transfer is considered. The analogy between heat transfer and momentum transfer is used to predict rates of heat transfer from the energy loss and the flow mechanism. Recent work on the calculation of heat-transfer coefficients from velocity profiles is presented for flow in simple conduits—namely, circular tubes and annuli. In the section of heat transfer, circular tubes and annuli are considered in greater detail than flow in other conduits or over immersed bodies. The bulletin concludes with a table of nomenclature, a bibliography of 129 references, and a detailed index of subjects.

ELECTRONICS

Industrial Electronics. R. Kretzmann. Houston, New York, Elsevier Press, Inc., 1953. 236 pp., illus., diagrs., figs. $5.50.

The first part of this book is devoted to a treatment of the scientific principles of vacuum and gas-filled electronic tubes and their basic circuits. The second part deals with industrial applications such as electronic relays, counting circuits, timers, rectifiers, speed and temperature controls, motor control, and dielectric heating. The author is associated with Philips' Gloeilampenfabrieken, Eindhoven, The Netherlands.

Television and Radar Encyclopaedia. Edited by W. MacLanachan. 2nd Ed. New York, Pitman Publishing Corporation, 1954. 216 pp., illus., diagrs., figs. $6.00

This reference book of terms in common use in Great Britain and the United States has been improved by the addition of new terms and the revision of others to reflect current practice.

MATHEMATICS

Tables of Integral Transforms, Vol. 2, Based, in Part, on Notes Left by Harry Bateman and Compiled by the Staff of the Bateman Manuscript Project. Prepared at California Institute of Technology under Contract with the Office of Naval Research. New York, McGraw-Hill Book Company, Inc., 1954. 451 pp. $8.00.

This is the second of two volumes of tables of integrals involving higher transcendental functions, designed for the use of mathematicians, physicists, and engineers. The two volumes contain tables of all integral transforms frequently used in pure and applied mathematics and in engineering. This volume contains Hankel transforms whose kernel is a Bessel function, fractional integrals, Stieltjes and Hilbert transforms, and a collection of integrals of higher transcendental functions. Some results included in the tables have been extracted from standard literature; others have been taken from sources that were not readily accessible; and many of them are entirely new. The work is so planned that the practical mathematician, the physicist, or the engineer can evaluate integrals with a minimum of labor. Although prepared to be used with *Higher Transcendental Functions*, each volume of the tables may be used separately. All notations are explained in an appendix, thus making the user of the tables independent of the other volumes.

For information on IAS Library Service Facilities, see page 93.

Statements and opinions expressed in Book Reviews are to be understood as individual expressions and not necessarily those of the Institute.

MECHANICS

Studies in Mathematics and Mechanics; Presented to Richard von Mises by Friends, Colleagues, and Pupils. New York, Academic Press, Inc., 1954. 353 pp., figs. $9.00.

This volume contains 42 papers presented to Professor von Mises on the occasion of his seventieth birthday. The papers are divided into five main groups: (1) Algebra and Number Theory, Geometry; (2) Analysis; (3) Theoretical Mechanics; (4) Applied Mechanics; and (5) Probability and Statistics. The papers on mechanics are as follows:

Some Considerations on Turbulent Flow with Shear, J. M. Burgers. An Example of Axially Symmetric Flow with a Free Surface, P. R. Garabedian. On a Class of Spherically Symmetric Flows, G. Kuerti. On Periodically Oscillating Wakes in the Oseen Approximation, C. C. Lin. Some Bounds for the Critical Free Stream Mach Number of a Compressible Flow Around an Obstacle, Charles Loewner. Two Topics in One-Dimensional Gas Dynamics, G. S. S. Ludford. On the Stroboscopic Method, N. Minorsky. Estimates for Eigenvalues, G. Polya. On Slow Visco-Plastic Flow, William Prager. Relativistically Rigid Surfaces, J. L. Synge. Certain Aspects of Plastic Flow under High Stresses, P. W. Bridgman. Natural Convection Heat Transfer Correlation, Howard W. Emmons. Der Senkrecht zu seiner Ebene belastete, elastisch gebettete Kreisträger, Karl Federhofer. On Inelastic Thermal Stresses, Alfred M. Freudenthal. Torsion of a Circular Cylindrical Body by Means of Tractions Exerted upon the Cylindrical Boundary, H. Reissner and E. Reissner. Una Espressiva Applicazione delle Proprietà di Media dello Stress Comuni a Tutti i Sistemi Continui, A. Signorini.

METALS & ALLOYS

Strength and Resistance of Metals. John M. Lessells. New York, John Wiley & Sons, Inc., 1954. 450 pp., illus., diagrs., figs. $10.

The aim of this volume is to provide the college senior and graduate student, as well as the design engineer, with information on the behavior of metals under stress as it has been revealed by numerous workers in this field. This information includes some of the author's contributions drawn from his experience in various fields of mechanical engineering. Most of the discussion centers around the behavior of steel as the prime material of engineering products. Mention is made, however, of nonferrous alloys and cast iron where their behavior differs from that of steel. Use

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has been made of information and data presented by S. Timoshenko in an earlier work and by H. J. Gough in papers and lectures. The author is President, Lessells and Associates, Inc., Engineers, and Associate Professor of Mechanical Engineering, Emeritus, M.I.T.

Contents: (1) Tension. (2) The Elastic-Stage Modification. (3) Tensile Properties at Elevated Temperatures. (4) Hardness. (5) Impact. (6) Fatigue—Normal Conditions. (7) Fatigue—Controlling Factors. (8) Fracture of Metals. (9) Strain Hysteresis. (10) Mechanical Wear. (11) Theories of Strength and Working Stresses.

Nickel in Iron and Steel. A. M. Hall. (Alloys of Iron Research Monograph Series.) New York, Published for the Engineering Foundation by John Wiley & Sons, Inc., 1954. 595 pp., diagrs., figs. $10.

Nickel in Iron and Steel reviews and correlates all of the important published data on nickel as an alloying element in steel and cast iron. Nearly 800 papers (listed in the bibliography at the end of the book) were reviewed for this manuscript. The introduction is concerned with the occurrence and refining of nickel ores. The rest of the book contains material on such topics as: the physical properties of steels containing nickel; the structure and heat treatment of wrought and cast nickel steels; and the effect of nickel on various engineering properties. Corrosion and the welding of nickel steels are discussed in detail. The effect of nickel on the constitution of cast iron, its tensile strength, and its hardness are a few of the other important subjects treated in this volume. Each chapter is concluded with a summary. The author is Chief, Alloy Development Division, Battelle Memorial Institute.

Modern Electroplating. Edited by Allen G. Gray. Sponsored by the Electrochemical Society, Inc. New York, John Wiley & Sons, Inc., 1953. 563 pp., illus., figs. $8.50.

A comprehensive, up-to-date presentation of theory and practice, compiled by 39 authorities. References follow each chapter.

METEOROLOGY

Thunderstorm Electricity. Edited by Horace R. Byers. Chicago, The University of Chicago Press, 1953. 344 pp., illus., diagrs., figs. $6.00.

The Geophysics Research Directorate of the Air Force Cambridge Research Center supported and sponsored the research reported in this volume.

Introduction, Horace R. Byers. The Atmospheric Electric Field and Its Meteorological Causes, H. Israel. Investigations of the Potential Gradient at the Earth's Ground Surface and within the Free Atmosphere, L. Koenigsfeld. Thunderstorm Structure and Dynamics, Horace R. Byers and R. R. Braham, Jr. Observational Data on the Formation of Precipitation in Cumulonimbus Clouds, Helmut Weickmann. Structure and Electrification, E. J. Workman and S. E. Reynolds. Experimental Contributions to the Knowledge of Charge Generation, Leonard B. Loeb. Measurements of the Electricity Carried by Precipitation Particles, Ross Gunn. Thundercloud Electrification in Relation to Rain and Snow Particles, Seville Chapman. Aircraft Measurements of Electric Charge Carried to Ground through Thunderstorms, G. R. Wait. Charge Distribution and Electrical Processes Deduced from Lightning Measurements, D. J. Malan and B. F. J. Schonland. Field Changes Due to Lightning Discharges, E. T. Pierce and T. W. Wormell. Simultaneous Measurement of Sferics Signals and Thunderstorm Activity, Robert E. Holzer. Long-Distance Location of Thunderstorms, Harald Norinder. Aircraft and Lightning, Morris M. Newman. Power-Line Protection, E. L. Harder and J. M. Clayton.

MISSILES

Tables for Rocket and Comet Orbits. Samuel Herrick. (National Bureau of Standards, Applied Mathematics Series, No. 20.) Washington, Superintendent of Documents, 1953. 100 pp. $1.75.

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Development of the Guided Missile. Kenneth W. Gatland. 2nd Ed. London, Published for *Flight* by Illiffe & Sons, Ltd.; New York, Philosophical Library, 1954. 292 pp., illus., diagrs., figs. $4.75.

New chapters deal with problems of propulsion, research into rocket techniques and requirements, and postwar work on guided bombs. There is a survey of Russian potentialities for long-range rocket development. An appendix reveals some details of the telemetering equipment used in British missiles, and another appendix shows photographs, to scale, of over 40 notable rockets from various countries. The table of characteristics, which was an important feature of the first edition, has also been enlarged and now provides data on 140 powered rockets from eight countries.

PHYSICS

Methods of Mathematical Physics. Vol, 1. R. Courant and D. Hilbert. First English Edition. Translated and Revised from the German Original. New York, Interscience Publishers, Inc., 1953. 561 pp. $9.50.

This edition contains a large number of additions and modifications but still retains the objective of the original edition. It aims to strengthen the connection between mathematics and physics and to reunite divergent trends by clarifying the common features and interconnections of many distinct and diverse scientific facts. The present work is designed to serve this purpose for the field of mathematical physics. Mathematical methods originating in problems of physics are developed, and the attempt is made to shape results into unified mathematical theories.

POWER PLANTS

Engineering Dynamics, Vol. 4, Internal Combustion Engines. C. B. Biezeno and R. Grammel. Translated from the Original German by M. P. White. (Engineering Dynamics, Vol. 4.) London, Blackie & Son Limited. 1954. 282 pp., diagrs., figs. 50*s*.

This translation, which has been made from the 1931 edition of *Technische Dynamik*, has also been brought into conformity with a second edition published in 1953 and has been read by Professor Biezeno. The present book covers some of those static and kinetic problems that engineering practice has to solve by the scientific methods of mechanics. In spite of the importance the authors have attached to numerical results, they have given prominence to the methods of solution, and a whole chapter has been devoted to a study of methods. Solutions are not given merely in outline, but the details have been developed in the way in which a designer must execute his calculations. Elementary engineering mechanics has been excluded, it being presumed that the reader knows that subject and its accompanying mathematics.

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Les Petites Turbines à Gaz de 30 a 300 Ch. (Small Gas Turbines, 30–300 Hp.) Henry Lanoy. Paris, Girardot & Cie., 1954. 128 pp., illus., diagrs., figs. 980 fr. (In French.)

A summary of the status of the small gas turbine and its applications in the automotive, aeronautical, marine, and industrial fields. The first chapter sketches the history and evolution of the gas turbine. Here the author has included tables showing the properties of high-temperature materials and a comparison of different types of heat engines. Chapter 2 is a summary of the principles underlying the design and operation of gas turbines. The third chapter is devoted to descriptions of existing makes: the Turbomeca Oredon and Artouste; the Boeing 502; the S.O.-C.E.M.A. Cematurbo; the AiResearch; the Rover; the Solar; and the small turbines that are part of the Wright Turbo-Compound. Ample use has been made of diagrams and curves to show installation features and performance. The potentialities of the small turbine are discussed in Chapter 4. Chapter 5 is an abridged translation of a paper by H. C. Hill on the use of the small Boeing turbine in a Kenilworth truck tractor. The final chapter is concerned with various methods of starting.

Moteurs à Réaction. Gaston Lavoisier. Paris, Technique et Vulgarization, 1952. 236 pp., illus., diagrs., figs. 1340 fr. (In French.)

A presentation—for the engineer, pilot, and technician—of the theory, contruction, operation, and application of all types of reaction propulsion power plants.

STRUCTURES

Characteristics and Applications of Resistance Strain Gages. Proceedings of the NBS Semi-centennial Symposium on Resistance Strain Gages Held at the NBS on November 8 and 9, 1951. (National Bureau of Standards, Circular No. 528.) Washington. Superintendent of Documents, 1954. 140 pp., illus., diagrs., figs. $1.50.

The papers presented at this Symposium represent some of the latest results, both experimental and theoretical, in studies made by many leading institutions in the United States and abroad. The Office of Naval Research participated in the Symposium.

Contents: Poisson-Ratio Determinations for Elastic and Plastic Strains of Tensile Specimens, Irwin Vigness and T. E. Pardue. Cementing and Waterproofing of Resistance Strain Gages. R. G. Boiten. Unbonded Resistance-Wire Strain Gage, Louis Statham. An Imbedded Bonded-Wire Resistance Strain Gage for Measuring Internal Strain in Concrete, Rudolph C. Valore, Jr. Properties of Concrete under Impact as Measured with Bonded-Wire Strain Gages, David Watstein. A New Strain Gage Without Transverse Sensitivity, A. U. Huggenberger (Abstract). How to Use G-H Gages, Gotthard V. A. Gustafsson. Bonded-Wire Strain Gage in the Field of Instrumentation, Arthur C. Ruge. Commercial Weighing with Resistance Strain Gages, Arthur L. Thurston. Application of Resistance-Wire Strain Gages to High-Capacity Load-Calibrating Devices, D. R. Tate. Preliminary Investigation of the Strain Sensitivity of Conducting Films, William R. Campbell.

IAS News, *Members Elected*

(*Continued from page 90*)

Voss, Herbert M., Sc.D., 2nd Lt., USAF.

Vrebalovich, Thomas, Ph.D., Research Engr., Jet Propulsion Lab., California Institute of Technology.

Warren, Charles A., B.M.E., Lt., USAF; Asst. Proj. Officer, Holloman AFB.

Watkins, Charles Lee, B.S. in M.E., Jr. Engr., Douglas Aircraft Co., Inc. (Long Beach).

Webster, Lee Francis, B. of Ae.E., Proj. Engr., Wind Tunnel, Jet Propulsion Lab., California Institute of Technology.

Weiner, Robert I., B.A.E., Research Aerodynamics Engr., Grumman Aircraft Engineering Corp.

Wilmot, Russell A., B.S.M.E. (Aero.), Assoc. Engr., Stress Analyst, Bel Mar Engineering Labs.

Wilson, Michael E., B.S.Ae.E., Experimental Test Engr., Allison Div., General Motors Corp.

Windler, Milton L., B.S. in Ae.E., Aero. Research Intern, NACA, Langley AFB.

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